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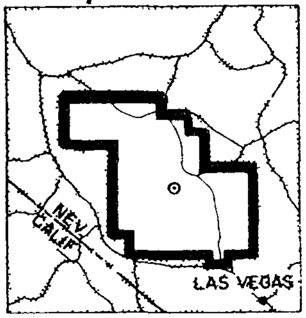

NEVADA TEST SITE
MAY - OCTOBER 1957

OPERATION PLUMBBOB

Projects 37.1, 37.2, 37.2a, 37.3 and 37.6

DISTRIBUTION, CHARACTERISTICS, AND BIOTIC AVAILABILITY OF FALLOUT, OPERATION PLUMBBOB

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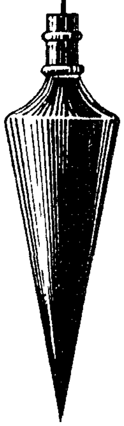
RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS



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Report to the Test Director

DISTRIBUTION, CHARACTERISTICS, AND BIOTIC AVAILABILITY OF FALLOUT, OPERATION PLUMBBOB

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ABSTRACT

This report includes the significant findings of CETO Program 37, related to the distribution, characteristics, and biological availability of fallout debris originating from the Plumbbob Test Series (1957) at the Nevada Test Site.

The use of aerial radiometric survey was adapted to routine radiation surveys and greatly increased the detail, accuracy and distance of fallout pattern delineation. Isodose rate and time-of-arrival contour maps are presented for seven tower mounted and four balloon mounted shots along with the predominant particle size fraction on several arcs along each fallout pattern.

Particles less than 44 microns in diameter contained about 30 percent of the fallout radioactivity from tower mounted detonations as compared to about 70 percent from balloon mounted detonations within distances at which fallout arrived by H + 12 hours. Balloon mounted detonations produced fallout debris of higher water and acid solubility than did tower mounted detonations.

The percentage of $Sr^{89,\ 90}$ and $Ru^{103,\ 106}$ was higher in fallout particles less than 44 microns in diameter than in larger fallout particles. There was a higher percentage of these radioelements in fallout debris from balloon detonations than from tower detonations. The amounts of water-soluble Ba^{140} and $Sr^{89,\ 90}$ deposited by a balloon mounted and a tower mounted detonation of similar yield and height of burst were estimated to be similar despite relatively large differences in the total amounts of these radioisotopes deposited. Within distances at which fallout occurred by H + 12 hours, balloon mounted detonations deposited a maximum of 0.13 percent of the theoretical total of Sr^{89} produced while tower mounted detonations deposited a maximum of 2 percent. Tower mounted detonations deposited a maximum of 7.2 percent of the theoretical total amount of Sr^{90} produced.

Decay of beta radiation approximated the $T^{-1.2}$ decay expression from H + 12 to H + 6000 hours; decay of gamma radiation deviated to the extent that doses calculated by the observed decay values were 1.8 to 2 times greater than those calculated by the $T^{-1.2}$ relationship. There were also significant differences in the gamma energy spectrum with time after detonation.

In the environment, fallout radioactivity was apparently confined to the upper 2 inches of soil unless the soil was mechanically distributed. The majority of the fallout debris which was redistributed by environmental factors on the soil surface after original

deposition consisted of less than 44 micron diameter particles; this size particle also represented the predominant contamination on forage plants. Strontium^{90} surface soil contamination levels in Nevada and Utah in August 1958, ranged from 32 to 142 mc/mi^2 in virgin areas near known fallout pattern midlines and from 7.5 to 28 mc/mi^2 in agricultural areas which did not necessarily coincide with fallout pattern midlines.

During this Test Series Operation, the level of uptake of I^{133} and I^{131} by native animals was a function of distance from ground zero. Ba^{140}, Ru$^{103, 106}$ and Sr$^{89, 90}$ were major bone contaminants. Post-series sampling of native animals indicated that the level of uptake of Sr^{89} was also a function of distance; however, uptake levels of Sr^{90} correlated poorly with total soil contamination. Milk samples collected from Nevada and Utah farms before, during, and after the Plumbbob Test Series showed that strontium levels increased in milk immediately following contamination of the farm with fallout debris and then decreased with time.

Studies clearly indicated that accumulation of radionuclides by mammals cannot be assessed only on the basis of dose rate measurements of the gamma radiation field. Radionuclides from radioactive fallout debris are assimilated by animals with the maximum degree of accumulation occurring not necessarily near ground zero. Furthermore, within a distance of 10 to 400 miles from the Nevada Test Site, the plant foliage is a selective collector of small size fallout particles within the less than 44 micron fraction and is the primary source of radionuclides to foraging animals. No significant accumulation of radionuclides through the root system of plants has been observed in this area during the sampling periods following fallout deposition. Biological availability of fallout debris is strongly influenced by the distribution of fallout contamination and by the physical and chemical nature of the fallout material and its interaction with climatic, biotic, and edaphic factors.

The data suggest that the higher levels of Sr^{90} in the indigenous animals are associated with animals that were living in the early sequence of contamination, i.e., during and immediately after fallout, rather than with animals that were born later and merely lived in the contaminated environment.

ACKNOWLEDGMENTS

This report is published in the interest of providing information which may prove of value to the reader in his present-day studies and evaluation of available data on phenomenology of fallout from above ground surface nuclear detonations. The document is the product of the efforts of many individuals and their devoted interest. While many suggestions, recommendations, and revisions contributed to this report, errors in fact or judgment can only be attributed to the senior author.

The authors* gratefully extend their thanks to the personnel and their organizations whose efforts and contributions made it possible to present this report. We are especially indebted to the late Dr. A. C. Graves, former Chairman of the Planning Board, Weapons Test Programs, for his evaluation and recommendation that this program be given adequate technical and financial support and to Mr. James Reeves, Test Manager, and his able staff whose support included supplementary budgets, meteorological data, laboratory facilities at Mercury, and aircraft for radiometric surveys and communications.

Special thanks and sincere appreciation are due Dr. C. L. Dunham, Director, and to Mr. R. L. Corsbie (former CETG Director), Division of Biology and Medicine, USAEC, for their assistance and support in all phases of this program. Dr. Dunham's support throughout the ten years since this program was first outlined in 1956 is a primary factor in bringing this document to completion.

We are indebted to the two former Directors of the Laboratory of Nuclear Medicine and Radiation Biology, Dr. Stafford L. Warren and Dr. J. F. Ross and their staff. Dr. Warren and his administrative staff, Mr. R. J. Buettner, Mr. J. D. Nelson, Mrs. D. White, to name a few, were exceptionally responsive to the needs of this

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complex program during the staging and initial operational phases. Dr. Ross gave a great deal of his time and energy to the final phases. In addition, he and Dr. Dunham made it possible to transfer on July 1, 1965 all records, files, and samples pertaining to this as well as the pre-1957 UCLA field programs to the Environmental and Radiological Sciences Department of the Pacific Northwest Laboratory operated for the Atomic Energy Commission by Battelle Memorial Institute at Richland, Washington. This arrangement provided a continuation of certain studies that are of interest to USAEC and other agencies. For this reason, the final editing and reproduction of this report were completed at Battelle-Northwest, the present address of the senior author.

The dedicated assistance, guidance, and helpful evaluation of Dr. A. W. Bellamy throughout this effort are gratefully acknowledged. During much of this time, he served as advisor to the Laboratory of Nuclear Medicine and Radiation Biology, particularly to our program.

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CHAPTER 1

INTRODUCTION

The assessment of biological hazards resulting from radioactive fallout produced by detonations of nuclear devices presents a problem that may be arbitrarily but incompletely divided into two phases One phase is concerned with the acute or immediate hazards arising primarily from sources of radiation external to the biota and secondarily from the biotic accumulation of certain radionuclides classified as internal emitters. The other phase involves the chronic or long term hazards arising primarily from irradiation by internal emitters and secondarily from external radiation. These phases may be related to distance from ground zero or the time of deposition of fallout in the biosphere. Although the duration or effect of each phase is indefinite or incompletely known, such a division provides a focus of attention for a convenient experimental and observational approach to the assessment problem

The assessment and analysis of biological hazard problems involves an identification and definition of those physical, chemical, radiological and biological parameters which jointly comprise the fallout phenomenon. A determination of the manner in which such parameters are influenced by inherent variations in nuclear detonations such as yield, height, and type of test device support, would provide the information essential to the construction of a fallout model system based upon clearer understanding of fallout mechanics Such a model could then be used to predict fallout patterns, allowing for an adequate interpretation of the significance of (a) time of arrival of fallout debris, (b) radiation-intensity levels, and (c) particle characteristics, per se, on the several biological systems acutely and/or chronically exposed within a given fallout pattern

During Operation Plumbbob, an assessment program was designed to study three groups of problems in more detail and to greater distances from ground zero than had been studied during the previous continental test series These problems were classified as follows (1) the delineation and characterization of fallout patterns, (2) the radiological, physical, and chemical properties of fallout debris within these patterns, and (3) the evaluation of biological availability and accumulation or radionuclides associated with fallout debris in the biota within these patterns.

During the planning phase of Program 37, numerous discussions and reviews were held with representatives from the Los Alamos Scientific Laboratory (LASL), Lawrence Radiation Laboratory (LRL), Fallout Prediction Unit (FOPU) of the Test Manager's Organization, Division of Biology and Medicine (DBM) of the USAEC, and this Laboratory of Nuclear Medicine and Radiation Biology (NMRB), formerly the Atomic Energy Project of the University of California at Los Angeles (AEP/UCLA).

So far as was possible, the scope and objectives of this program included studies of common interest. Several objectives which were included resulted from uncertainties in measurements made during earlier test series. The objectives and project designations are presented below.

1.1 OBJECTIVES

1.1.1 Delineation and Characterization of Fallout Patterns

A detailed fallout-pattern delineation and characterization, relative to particle size distribution and detonation characteristics, required the accomplishment of the following objectives by Project 37.2a

(1) Delineation of fallout patterns with respect to radiation intensity and/or dosage levels out to distances corresponding to fallout time-of-arrival of H + 12 to H + 16 hours.

(2) Determination of time-of-arrival of radiation and/or fallout.

(3) Determination of dose rate during and after fallout.

(4) Determination of beta and gamma activities per unit surface area.

(5) Determination of particle size distribution and comparison to predicted particle size distribution along the pattern.

1.1.2 Characteristics of Fallout Debris

The second group of studies, i.e., a detailed analysis of fallout materials by Project 37.2, included the following specific objectives.

(1) Determination of both the beta energy and gamma energy spectra and the decay properties of fallout debris of specific particle size fractions and fallout time-of-arrival.

(2) Determination of the radioactivity-per-particle relation as a function of size and fallout time-of-arrival.

(3) Determination of solubility characteristics of radionuclides associated with fallout debris relative to particle size and fallout time-of-arrival.

(4) Determination of isotopic fractionation by radiochemical analyses for radionuclides of barium, cerium, cesium, ruthenium, strontium, yttrium, zirconium, with respect to selected particle size fractions and/or fallout time-of-arrival.

(5) Determination of such physical characteristics of fallout particles as magnetic properties, shape, color, and general appearance.

(6) Evaluation of the relative efficiencies of three different types of fallout collectors, i.e., gummed paper, nondrying resin plates, and granular collectors, with respect to unit area of surface soil and fallout time-of-arrival.

(7) Determination of the differences among field measurements of gamma-radiation intensity obtained with five available types of survey meters.

(8) Measurement and determination of the influences of environmental factors such as wind, temperature, humidity, and terrain, on the resuspension and

redistribution of fallout debris, including aerosol concentrations of radioactivity.

1.1.3 Biotic Availability of Fallout

Another group of studies relative to biological availability of fallout was the primary responsibility of Project 37.1. The documentation of some of the many ecological relationships within a given residual fallout pattern necessitated completion of the following objectives

(1) Determination of the persistence of fission products in tissues of native rodents and lagomorphs (rabbits), with special emphasis on the identification of radionuclides of barium, cerium, cesium, iodine, ruthenium, strontium, yttrium and zirconium.

(2) Determination of the influence of yield of detonation and the height, type, and kind of device support on the biological fate and persistence or radioactive debris at various distances along the midline of the fallout pattern.

(3) Determination of the persistence and physical characteristics of fallout particles retained on vegetation surfaces of range forage plants.

(4) Evaluation of the importance of radioactive decay relative to environmental decay (natural weathering processes plus radioactive decay) in modifying the concentration of initially deposited radioactive debris.

(5) Measurement of the beta versus gamma dose levels in several microenvironments at several intervals following fallout deposition.

(6) Serial documentation of selected persistence study areas for a period of three years following this Test Series to obtain data showing the relative importance of time with respect to the biological accumulation of Sr^{90} and Cs^{137}.

Relative biotic accumulations of radionuclides were documented with respect to fallout time-of-arrival along the midline of the fallout patterns, along various arcs lateral to the midlines, and in isolated hot spots as compared to adjacent areas of lower activities.

1.1.4 Assessment of the Availability of Fallout Material in Agriculture Systems

The primary responsibility of Project 37.3 was to obtain data on the initial distribution, the persistence within various components of the farm environment, and the initial biological availability of radionuclides from fallout deposited in agricultural areas as a result of nuclear detonations at the Nevada Test Site (NTS). These studies were dictated by a need for field data on the potential consequences to man of nuclear fallout in agricultural areas. An attempt was made to document quantitatively the distribution and uptake of radionuclides from fallout debris following contamination of an agricultural system in order to define the quantity of internal emitters transmitted to man from these environments.

Assessment of the overall problem required an achievement of the following objectives

(1) Determination of the soil contamination from fallout and its redistribution by existing management practices and environmental processes.

(2) Determination of the degree of fallout interception by certain agricultural crops and the persistence of radioactive debris on leaf surfaces in comparison to fallout deposited on native and agricultural soils.

(3) Determination of the amount of fallout contamination of feeds, forage, and pasture commonly consumed by cattle, with emphasis on Sr^{90} and Cs^{137} content.

(4) Determination of the metabolized isotopic content of animal products consumable by man, with particular reference to milk products.

This project represented the preliminary phase of a long term study to evaluate the significance of fallout contamination of agricultural systems.

1.1.5 Application of Environmental Assessment Techniques

An ancillary undertaking within the integrated studies of Program 37 was Project 37.6, designed primarily as a training program. The objective was to train personnel from various scientific disciplines in the techniques of environmental assessment and their practical application under fallout conditions. This training was intended to provide these personnel with knowledge and experience concerning the fallout problem as it is related to the soil-plant-animal-man cycle.

Seminars, formal lectures, and rotating project assignments were organized and integrated with the Program's operational schedule. The participating personnel included representatives from U. S. Air Force (veterinarians), U. S. Department of Agriculture (veterinarians), Food and Drug Administration (biologists) and graduate students in veterinary medicine and biology from several universities.

1.2 BACKGROUND

Previous studies of the fallout phenomena were conducted (by this Laboratory) during and/or after the following Test Series: TRINITY (1945), BUSTER-JANGLE (1951), TUMBLER-SNAPPER (1952), UPSHOT-KNOTHOLE (1953), and TEAPOT (1955). These studies were concerned primarily with fallout from the detonation of tower supported nuclear devices.

The annual radiological and biological surveys, from 1947 to 1951, of the ground zero area and the fallout pattern of Shot Trinity became the bases for this Laboratory's concept of environmental assessment of contaminated landscapes. For example, it was found that fallout was not distributed uniformly over the landscape. there were islands of radioactivity, or hot-spots, in the fallout pattern, the accumulation of radionuclides in mammals did not correlate with dose-rate measurements along the fallout pattern, solubility of the fallout debris and soil properties were important factors necessary to evaluate the persistence of fallout contamination on the ground surface. These and other observations and data have been reported (References 1 through 6).

In November 1951, observations and measurements were made during and immediately after fallout had been deposited in an area 6 to 40 miles downwind from the surface and underground detonations of the Buster-Jangle Series (1951) These measurements included determinations of the radionuclides that were available to crop plants from this type of fallout debris (References 7 and 8).

Beginning with the Tumbler-Snapper Series (1952) through the Upshot-Knothole Series (1953) and the Teapot Series (1955), both new and continuing studies were conducted in the NTS environs relative to the distribution of fallout and its properties. In 1952, studies were conducted on fallout deposition from three detonations at distances of 10 to 50 miles from ground zero (Reference 9), in 1953, from five detonations at 10 to 80 miles from ground zero (Reference 10), and in 1955, from six detonations at 10 to 160 miles from ground zero (Reference 11).

During the Upshot-Knothole Series, an exploratory effort was made to integrate studies of physical and radiological characteristics of fallout with biological availability assessments in fallout patterns (Reference 12). It was confirmed that realistic assessments of fallout contamination could be made only when biological availability measurements were integrated with studies of radiological distribution and characteristics of fallout debris

1 2.1 Delineation and Characterization of Fallout Patterns

Earlier studies were primarily concerned with tower-mounted shots and included the general delineation of the fallout patterns by survey-instrument monitoring and unit-area surface soil collections usually on three arcs (seven arcs on one shot) across the fallout patterns. The maximum distance sampled was 135 miles from ground zero which had measured fallout arrival time of H + 3.5 hours The maximum fallout arrival time measured was H + 9.2 hours which occurred at a distance of 132 miles. Both the dose rate and the unit-area surface activity measurements indicated a rapid decrease in fallout deposited downwind from detonations within a distance of 50 miles from ground zero Beyond 50 miles, the dose rate decreased asymptotically.

The integration of deposited fallout activity derived from dose rate and/or soil unit-area activity measurements along several arcs across fallout patterns studied during Upshot-Knothole (Reference 10) and Teapot Series (Reference 11) indicated a dependence on weapon yield and tower height. Measurements were made along lateral arcs crossing the fallout patterns at various distances corresponding to maximum fallout arrival times varying from H + 3.5 to H + 9.2 hours. The conditions of assessment were such that these relationships could be studied only at locations in the fallout pattern representing short intervals of time of fallout arrival. The time interval most common to a number of different fallout patterns was H + 0.8 to H + 2.2 hours

Results from particle size fractionation of soil samples indicated a general decrease in the median diameter of radioactive fallout particles out to a distance of 160 miles from ground zero. For example, the quantity of particles greater than 100 microns in diameter tended to decrease in concentration, whereas, the quantity of debris less than 100 microns in diameter tended to remain constant or to increase with greater distance within 160 miles from ground zero (References 10 and 11). In addition, the percent of radioactivity contributed by the less than 5 micron particle fraction showed an increase, e. g., from 3 to 4 percent at 20 miles and 10 to 12 percent at 150 miles on one shot (Reference 11).

The determination of the contributions of different radioactive fallout particle size ranges across a lateral indicated that, over the range of fallout times and distances from ground zero studied, the maximum contributions of radioactive particles as large as 125 microns in diameter and of particles less than 44 microns in diameter had not been reached. The latter size range is thought to be most significant biologically for reasons cited in Sec 1. 2. 3. Calculations based upon trajectory analysis indicated that patterns should be investigated at least to distances downwind from nuclear detonations corresponding to fallout arrival times of H + 12 to H + 16 hours in order to estimate the contribution of the smaller sized particle fractions in the deposited fallout.

Horizontal and vertical shear of the fallout cloud frequently occurs due to different wind structures during the time of cloud travel. Therefore, comparisons of fallout particle size distribution and other characteristics of fallout debris from different detonations should be based upon time of fallout arrival rather than upon distance from ground zero. Also the fallout arrival time along a pattern is basic to the estimation of radiation dosage During previous test series the time of fallout arrival was usually estimated on the basis of limited post shot wind speed and direction data and particle trajectory analysis was based on several poorly defined assumptions (References 10 and 11).

Thus, the extension of fallout pattern delineation in more detail and out to distances corresponding to fallout arrival time of H + 12 to H + 16 hours would serve: (1) to provide a more reliable comparison of detonation characteristics such as yield, height of detonation, and type or kind of weapon support, (2) to permit modification of fallout prediction models by interested organizations in order to increase the model's reliability, (3) to include the areas of maximum contribution of the smaller sized particle fractions (less than 50 microns) which are most significant in terms of biological availability of various radionuclides, and (4) to permit identification and detailed observations of hot spot areas.

1. 2. 2 Radiological, Physical, and Chemical Properties of Fallout Debris Collected from Documented Patterns

In many cases, a requirement for further definition and expansion of the data obtained from earlier studies was indicated. For example, the beta decay constants for a variety of detonations and sample types have shown definite deviations from the classical k-value of -1.2, as used in the expression $A = A_0T^{-k}$. These deviations were apparently time-dependent, for example, during the time period of H + 30 to H + 1000 hours, the beta decay slopes varied from -1.0 to -1.5 for Snapper aerosol and fallout samples (Reference 9). During Upshot-Knothole, the range of variation was found to be -1.2 to -1.7 over the time period of H + 100 to H + 1000 hours, and during Teapot, a range in decay slopes of -0.8 to -1 6 was obtained over various time intervals (References 10 and 11).

Such variations were also noted in beta energy determinations of fallout debris. For example, three maximum energy components were separated from the energy spectrum of Upshot-Knothole samples as follows: 0.21 to 0.52 MeV, 0.90 to 1.29 MeV, and 1 9 to 2.8 MeV (Reference 10). Analysis of Teapot samples, on the other hand, resulted in isolation of only two components, one ranging from 0.35 to 0.96 MeV, the other from 1.15 to 2.30 MeV (Reference 12). In addition, considerable variation was obtained in the Teapot ratios of beta microcuries per square foot to gamma mr/hr (μ/sq ft : mr/hr) at different distances and to a greater extent between different shots. Preliminary analysis of film dosimetry measurements made by the Health Physics Section, AEP/UCLA, during the Teapot series indicated that these ratio variations may have been at least partially attributable to differences in beta-gamma ratios inherent in fallout materials (Reference 13).

No comparable measurements were made by this Laboratory on the variability of the decay constant of the gamma radiation component of fallout samples. However, this information is essential for determining gamma dose to the populations indigenous to fallout patterns

More than 95 percent of the radioactivity associated with particle size fractions greater than 170 microns in diameter could be removed by magnet from samples of fallout debris from Shots Moth and Apple II, Teapot Series (Reference 11). However, only 3 to 5 percent of the activity could be removed from the 88 to 125 micron particle size fraction. These results and observed differences in the amount of tower and cab material remaining after various detonations, suggested that a method should be developed to measure the amount of tower and cab material which contributed to fallout

A limited number of solubility determinations made on radioactive particles from Upshot-Knothole fallout indicated that approximately one percent of the total radioactive material was soluble in water and two percent in 0.1 $\underline{N}$ HCl (Reference 10). Studies on Teapot samples indicated that 20 to 30 percent of the total activity was removed from soil samples by leaching with 0 1 $\underline{N}$ HCl, and that 60 to 80 percent of the activity associated with aerosols was removed with 0.1 $\underline{N}$ HCl (Reference 11). The difference in these results indicated that additional studies by improved methods were required to properly evaluate the solubility of fallout debris.

1 2.3 Biological Availability of Radionuclides Associated with Fallout Debris and Accumulation in Biota

The occurrence of fission products originating from radioactive fallout debris has been documented relative to the various components of local environments, including soil, flora, fauna, air, and the fallout materials per se (References 12 and 14) From data collected during and periodically after the test series, the cycling of fission products has been followed from one component of the environment to the other

Solubility is an index of the potential availability of fallout materials to the biological cycle. It was also shown that the radioactive fraction of particles less than 44 microns in diameter was relatively more acid soluble than that of the 100 micron diameter particles and this was more soluble than that of those particles larger than 100 microns. The majority of fallout particles retained on the leaves of forage plants were also observed to be less than 44 microns in diameter, with an average size of approximately 20 microns (Reference 14).

As could be predicted on the basis of the preceding observations, the radioactivity per unit weight of dry plant material collected at various distances from ground zero compared favorably with the distribution of the less than 44 micron fallout particle-size fraction However, radioactivity associated with plant material did not correlate well with the distribution of deposited fallout (Reference 14) Similarly, chronic burdens of fission products in tissues of animals collected from fallout patterns did not correlate well with dose rates of environmental contamination (References 12 and 14)

Inhalation has been shown by field and laboratory studies to be relatively insignificant as a pathway for biological accumulation of radionuclides from fallout debris (References 14 and 15) In addition, the variations in aerosol concentrations determined by several types of air samplers during Operations Tumbler-Snapper (Reference 9), Upshot-Knothole (Reference 10), and Teapot (Reference 11) could not be correlated with biological uptake

The assimilation of specific fission products by animals was highly variable and did not correlate well with the dose rate from fallout contamination For example, the body burden of radioiodine in desert rodents, collected during Teapot Series, was greater at 60 miles than at either 20 or 130 miles from ground zero (Reference 14) The body burden of radiostrontium in desert rodents six months following fallout was approximately five times greater at 130 miles than at six other locations sampled between 40 and 400 miles from ground zero within the fallout pattern from Shot-Met, Operation Teapot (Reference 17) A similar observation was made one year following Operation Upshot-Knothole in which the radiostrontium in native rodents was found to be seven times higher at a distance of 130 miles than in Yucca Flat The ratio of Sr^{89}

to Sr^{90} was variable in the bones of jack rabbits sampled along the midline of a residual fallout pattern These observations suggest a dependence of the chronic tissue burdens of radioactive debris on a particular particle size fraction rather than on total deposited fallout Time of fallout arrival and particle size determinations, therefore, seemed to be one approach needed to explain the variations in observed body burdens of fission products, however, additional studies were required to resolve the variations and their causes

In summary, a feasible explanation of the factors influencing the biological accumulation of radioactive fallout appeared to be that fission product assimilation is related to particle size and that, because the forage plants act as selective collectors of the small particle fraction (less than 44 microns in diameter), the ingestion of radioactive debris by animals during grazing is independent of total fallout. The amount of any specific isotope present is dependent upon the physical and chemical properties of fallout particles. Therefore, the amount of radionuclides associated with less than 50 micron particles at any particular location within the residual fallout pattern could be highly variable, and the occurrence of areas in which the biological accumulation of radionuclides is high should be anticipated.

The objectives of Project 37 1 were to determine the general validity, as well as to amplify this concept of biological accumulation of radioactive fallout

1 3 OPERATIONS

The integrated efforts of Program 37 were directed toward the stated objectives for a period from April to November 1957, at NTS This was accompanied and followed by a coordinated laboratory effort at AEP/UCLA, Los Angeles directed toward the analysis and evaluation of the data Some studies required several years to complete Table 1 1 shows the Shot Schedule of project participation of Program 37

TABLE 1 1 Schedule of Project Participation Program 37

No	Shot Name	Date	H Hour (PDT)	Projects Participating 37 1	37 2	37 2a	37 3	37 6
1	Boltzmann	28 May	0455	x	x	x		x
4	Wilson	18 June	0455		x	x		
5	Priscilla	24 June	0630	x	x	x	x	x
6	Hood	5 July	0440		x	x		
7	Diablo	15 July	0430	x	x	x		x
13	Shasta	18 August	0500	x	x	x		x
16	Smoky	31 August	0530	x	x	x	x	x
17	Galileo	2 September	0540		x	x		
21	Fizeau	14 September	0945		x	x		
22	Newton	16 September	0550		x	x		x
23	Ranier	19 September	1000		x	x		
24	Whitney	23 September	0530		x	x		x
Postseries Study				x	x		x	

1.3.1 Organization

The organization and interrelationships of five projects within Program 37 are presented in Figure 1.1. The coordinated efforts of approximately 100 field and Mercury laboratory personnel were required during the test series. The Project 37.2a field group, responsible for field surveys and the installation, operation, and recovery of sampling and monitoring equipment consisted of a maximum of 15 teams of two men each.

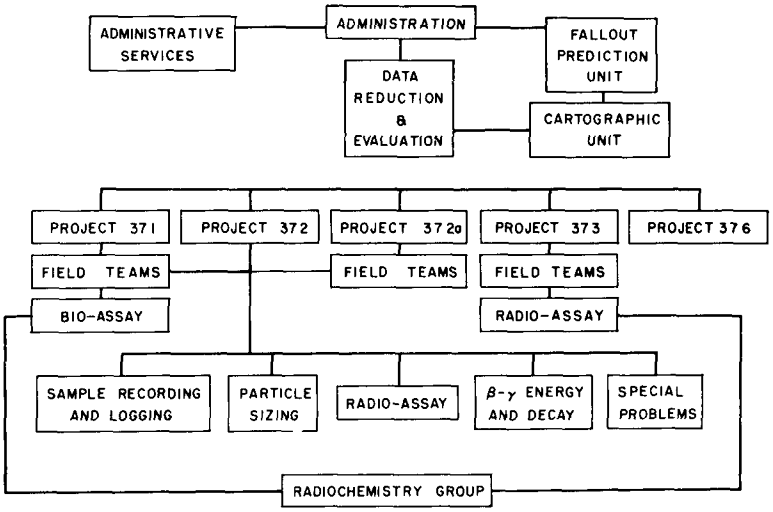

FIGURE 1.1 Program 37 Organization Chart

Assignment of field teams to areas of highest fallout probability and general coordination of field efforts were accomplished by use of radio and telephone communications. Detailed delineation of fallout patterns was accomplished by the U. S. Geological Survey (USGS) aerial radiometric techniques. Hot spots within the fallout patterns were further delineated when required by two Super Piper Cubs from the Raw Materials Division, AEC.

Field persistence studies (Project 37 1) were conducted by 4 four-man teams Pertinent data obtained by Projects 37.2a and 37.2 were also used to document the persistence study areas.

Project 37 3 utilized 1 two-man team for study of contaminated agricultural areas.

Personnel of Project 37.6 were rotated among the other field and laboratory groups as part of their training program

Laboratory processing at Mercury was accomplished by approximately 30 personnel assigned to Project 37.2. In addition, specific fission-product analyses were carried out by the Chemical Analysis Group at AEP/UCLA. A five-man group accomplished the reduction and evaluation of field and laboratory data.

A cooperative liaison was arranged and maintained with the Fallout Prediction Unit (FOPU) and the Air Weather Service Group both of the Test Manager's Organization to furnish Project 37.2a the necessary meteorological data and predicted mid-line fallout information. A group of 4 personnel from Program 37 was assigned the responsibility of maintaining the required exchange of data.

The administrative group provided the necessary direction and coordination of field and laboratory efforts, including the necessary logistic support.

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CHAPTER 2

THE DELINEATION AND DISTRIBUTION OF FALLOUT

2.1 INTRODUCTION

The delineation and distribution of fallout debris deposited in an area is the first essential phase of environmental assessment studies. This provides the basis for identification and definition of those physical, chemical, radiological and biological parameters which jointly comprise fallout phenomenology. This first phase is concerned primarily with: (1) documenting the geographical distribution and radiation level of contamination in the biosphere of the path of fallout deposition; and (2) measuring the time-of-arrival of fallout or radiation along the path of deposition. Data and their evaluation are presented for seven tower mounted and four balloon mounted shots.

2.2 PROCEDURE

Detailed description is given in Appendix A, Sections A.2.1, A.2.2, and A.2.3 of the methods and equipment used in this phase of study. It should be noted that the aerial radiometric survey techniques used by the U. S. Geological Survey (USGS) were adapted to monitoring fallout patterns on a routine basis for the first ime during this test series by this program.

2.3 RESULTS

Table 2.1 gives the total yield, type of device support, and the mean see level elevations of cloud top and base of each above-surface shot documented by Projects 37.2a and 37.2. Isodose-rate contours, the time-of-arrival of fallout, and an estimate of the predominant particle size fraction are shown below on maps of each fallout pattern.

TABLE 2.1 Project 37.2a and 37.2 Shot Participation, Device Support, Yield, and Cloud Height.

MSL, Mean Sea Level

Series No.	Shot Name	Date	H Hour, PDT	Type of Device Support	Height of Detonation, ft	Total Yield, kt[a]	Cloud Height, MSL, ft[a] Top	Base	Tropopause[a] MSL, ft
1	Boltzmann	28 May	0455	Tower	500	12	33,000	23,000	41,000
4	Wilson	18 June	0445	Balloon	500	10	35,000	25,000	40,000
5	Priscilla	24 June	0630	Balloon	700	37	43,000	24,000	49,000
6	Hood	5 July	0440	Balloon	1500	74	48,000	35,000	53,000
7	Diablo	15 July	0430	Tower	500	17	32,000	20,000	43,000
13	Shasta	18 Aug	0500	Tower	500	17	32,000	16,000	50,000
16	Smoky	31 Aug	0530	Tower	700	44	38,000	(20,000 Est)	35,000
17	Galileo	2 Sept	0540	Tower	500	11	37,000	17,000	39,000
21	Fizeau	14 Sept	0945	Tower	500	11	40,000	27,000	43,000
22	Newton	16 Sept	0550	Balloon	1500	12	32,000	19,000	52,000
23	Rainier	19 Sept	1000	Underground	-790	1.7	no cloud or venting		---
24	Whitney	23 Sept	0530	Tower	500	19	30,000	18,000	53,000

(a) From "Fallout Program Quarterly Summary Report," Report No. HASL-142, January 1, 1964, page 227, USAEC, Health and Safety Laboratory, New York.

2.3.1 Fallout Patterns

Isodose-rate contours at H + 12 hours and time-of-arrival of fallout and/or radiation are shown in Figures 2.1 to 2.12 for seven tower mounted and four balloom mounted detonations. The dose-rate values were measured during station recovery, from H + 24 to H + 30 hours, and corrected to H + 12 hours by data shown in Table A.2 and the Plumbbob Composite Decay Curve (Figure 4.11).

Boltzmann Fallout Pattern (Figure 2.1): This pattern is based upon Program 37 ground and aerial survey data and Off-Site Rad-safe ground survey results. The isodose-rate contours shown from ground zero to Arc I (approximately 35 miles) are estimated because of rough terrain and inaccessibility. The time-of-arrival of fallout after H + 5 hours is estimated on the basis of a few measured values and calculated cloud trajectories from the Fallout Prediction Unit (FOPU), Test Manager's Organization. Only aerial survey data were available at times-of-arrival of fallout greater than H + 9 hours.

The 100 mr/hr contour which defines the hot spot west of Warm Springs, Nevada, (approximately 76 miles from ground zero) is of particular interest. This area was characterized by having approximately 75 percent of the total activity associated with less than 44 micron material in the area of maximum dose rates (see Appendix C). There is the suggestion that the northern portion of a mountain ridge may have contributed to this deposition of the observed hot spot. There were no rain clouds observed in this immediate area by personnel of the radio-relay communication aircraft at H-40 minutes. The only rain clouds observed were approximately 20 miles to the west.

Wilson Fallout Pattern (Figure 2.2): This Shot was not originally scheduled for documentation, and Program 37 fallout measurements were obtained only by aerial survey. The pattern is based on these and Off-Site Rad-Safe ground survey data. There is some doubt as to the magnitude of fallout in the southwest portion of the pattern. Fallout time-of-arrival is based on cloud trajectory estimates by FOPU.

Priscilla Fallout Pattern (Figure 2.3): Dose-rate contours of this pattern are based on Program 37 ground and aerial survey data and some Off-Site Rad-Safe results. However, the isodose-rate contours between Arc I (Indian Springs Road) and ground zero are estimated. The time-of-arrival of fallout is based on measured values. The occurrence of isolated hot-spots and the predominance of less than 44 micron fallout material on all sampling arcs is of special interest. There was excellent agreement on the magnitude and location of the midline, the occurrence and location of the hot spots, and the dose-rate contours of the southern half of the pattern. However, there was only good agreement as to the location of the northern boundary of this pattern.

Hood Fallout Pattern (Figure 2.4): This pattern is based on Program 37 ground and aerial survey data. Some of the isodose-rate contours are estimated on the basis of the contamination levels measured in the fallout collectors (see Table 2.3 for conversion factors). The pattern is north of previous Plumbob contamination; therefore, the dose-rate values are reliable even though of low intensity. The pattern is characterized by hot spots and a predominance of less than 44 micron material, as in the case of Shot Priscilla.

Diablo Fallout Pattern (Figure 2.5): Program 37 ground and aerial survey and Off-Site Rad-Safe ground survey data were used to develop this pattern with good agreement beyond 100 miles. The isodose-rate contours on the western edge of the fallout pattern are estimates and may be located too far west. The lack of roads in this area precluded the collection of survey data. The time-of-arrival of fallout after H + 6 hours is estimated on the basis of the measured times and calculated cloud trajectories. The Diablo pattern shows a large hot spot east of Lund, Nevada. It was well documented.

Shasta Fallout Pattern (Figure 2.6): This pattern is based on On-Site Rad-Safe data pertinent to Shasta fallout in Yucca Flat, and Program 37 ground and aerial survey data for the area beyond NTS. Off-Site Rad-Safe data were not used. The isodose-rate contours shown are the net result after the appropriate deduction of residual contamination from Shot Diablo, especially on the eastern portion. Cloud trajectories were used to calculate the estimated time-of-arrival of fallout after H + 5 hours.

Smoky Fallout Pattern (Figures 2.7a, 2.7b, 2.8): Figures 2.7a and b present the detailed fallout pattern developed from Program 37 ground and aerial survey data from ground zero to northeastern Utah. Figure 2.8 shows the complete pattern from ground zero to Casper, Wyoming. The pattern is based on aerial survey data only, from Panguitch, Utah to the northeast. The pattern was still readily detectable at 700 miles from ground zero at D + 5 days. The fact that the time-of-arrival isopleths parallel the major axis of the pattern to a large extent is of particular interest and is probably the result of vertical shear. There were at least two hot spots delineated.

Galileo Fallout Pattern (Figure 2.9): Program 37 ground and aerial survey data are the basis for this pattern south of Highway 6. Off-Site Rad-Safe data were used north of Highway 6. The lack of complete monitoring data necessitated the estimation of the shape of the western edge and the close-in portion of this pattern.

Fizeau Fallout Pattern (Figure 2.10): This pattern is based on On-Site Rad-Safe data pertinent to the fallout in Yucca Flat and Program 37 ground and aerial survey data and Off-Site Rad-Safe data beyond NTS. The fallout time-of-arrival contours, both measured and estimated, compare favorably with FOPU calculated cloud trajectories.

Newton Fallout Pattern (Figure 2.11): Detected fallout levels were of very low intensity and are not reliable, therefore, this pattern is only an estimate. Where possible, dose rates were calculated from the granular fallout collectors. No measurements of time-of-arrival of fallout were obtained.

Whitney Fallout Pattern (Figure 2.12): This pattern is based on Program 37 ground and aerial survey data with the exception of the northernmost portion, above Mina, Nevada (east of Walker Lake), which is based on aerial data alone. No information relative to the radiation levels in Yucca Flat and adjacent terrain was obtained: therefore, this portion is an estimate.

All seven tower mounted shots produced areas beyond NTS with dose rates in excess of 100 mr/hr at H + 12 hours and, with the exception of Shots Boltzmann and Galileo, small areas in excess of 1000 mr/hr at H + 12 hours. In contrast, balloon mounted Shots Wilson, Hood, and Newton, having a range in total yield from 10 to 74 kt, resulted in dose rates of less than 10 mr/hr at H + 12 hours at all locations of measurement. Shot Priscilla, a balloon mounted device whose fireball nearly intersected its ground zero ground surface, resulted in dose rates ranging from 10 to 100 mr/hr at H + 12 hours. Table 2.2 presents a summary comparing the areas within selected isodose-rate contours of fallout patterns from balloon and tower mounted shots. There are no apparent relationships; additional analysis and interpretation of basic data of meteorological observations, environmental factors, particle size distributions, and dose-rate measurements are required.

TABLE 2.2 Areas Within Selected Isodose-Rate Contours of Fallout Patterns From Balloon and Tower Mounted Detonations

Dose rate measurements made H + 24 to H + 30 hours and corrected to H + 12 hours. EM, estimated and measure values, NC, not closed, ND not determined

Shot	Isodose-Rate Contours at H + 12 Hours						
	> 100	50-100	10-50	5-10	1-5	0.5-1	0.5-0.1
	Square Miles						
Balloon-Mounted							
Wilson, 500 ft (10 kt)	--	--	--	40 EM	704	2,940 NC	ND
Priscilla, 700 ft (37 kt)	--	60 EM	368	540	4,380 NC	ND	ND
Hood, 1500 ft (74 kt)	--	--	--	--	410 EM	2,315	11,915 NC
Newton, 1500 ft (12 kt)	--	--	--	--	--	125 EM	7,770 NC
Tower-Mounted							
Boltzmann, 500 ft (12 kt)	190 EM	390	1,348	1,510	8,310 NC	ND	ND
Biablo, 500 ft (17 kt)	400 EM	233	1,810	3,765	5,030 NC	ND	ND
Shasta, 500 ft (17 kt)	300 EM	162	727	1,421	6,830 NC	ND	ND
Smoky, 700 ft (44 kt)	470	283	2,267	1,645	4,230 NC	ND	ND
Galileo, 500 ft (11 kt)	104 EM	66 EM	525 EM	576 EM	3,110 NC	ND	ND
Fizeau, 500 ft (11 kt)	45 EM	46 EM	330 EM	635 EM	3,580 EM	ND	ND
Whitney, 500 ft (19 kt)	230 EM	120	854	1,308	7,950 EM	ND	ND

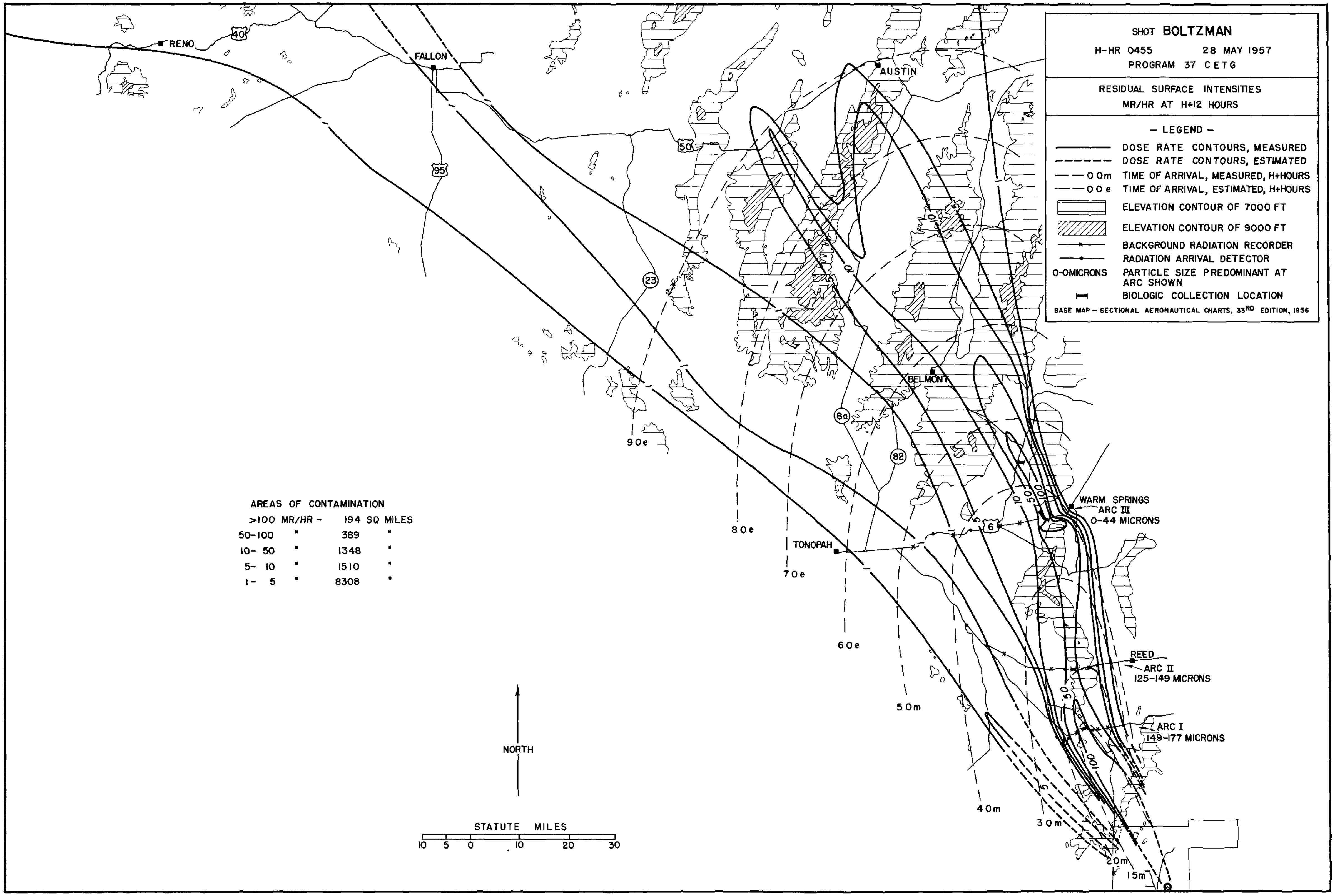


FIGURE 2.1 Boltzmann Fallout Pattern

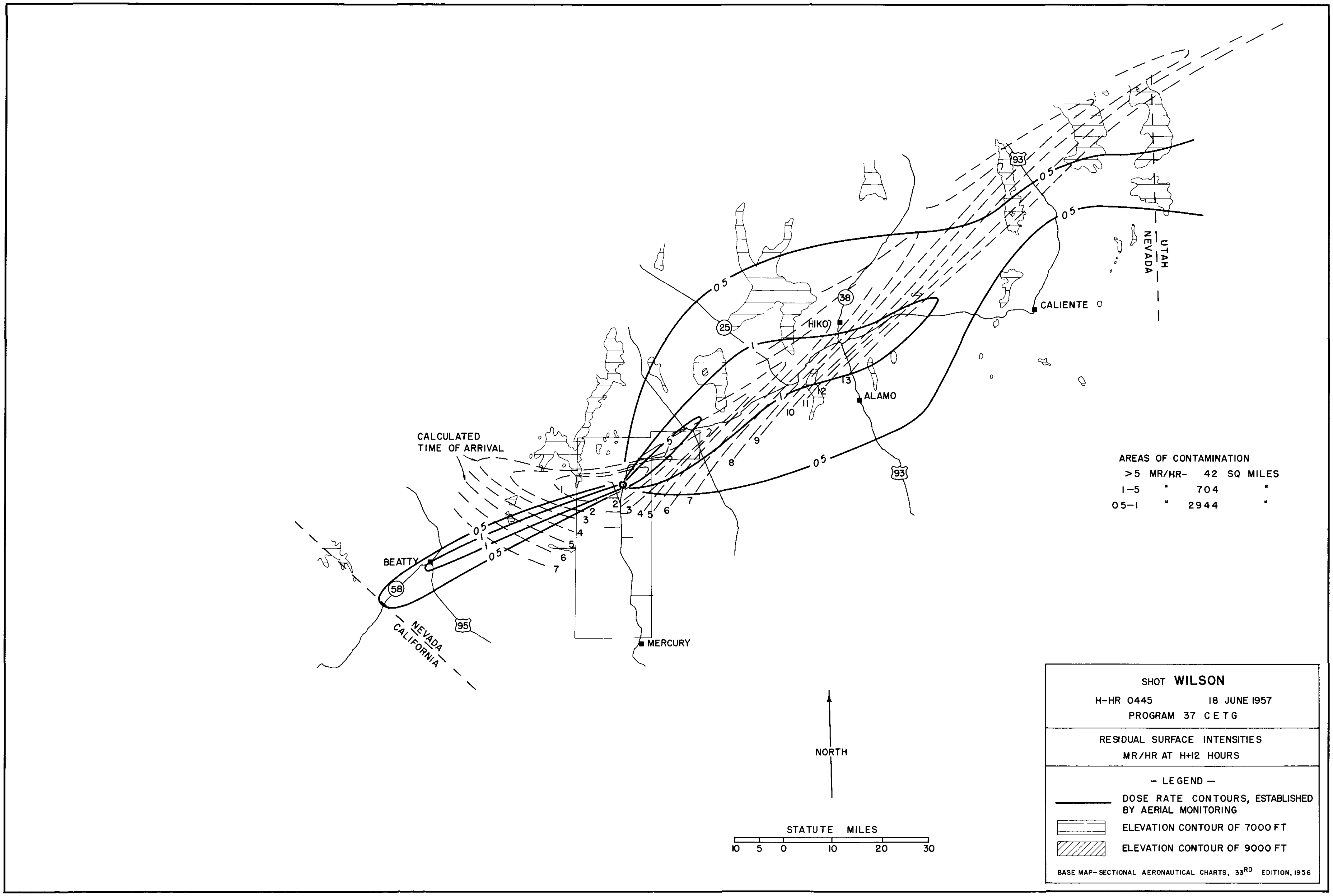


FIGURE 2 2 Wilson Fallout Pattern

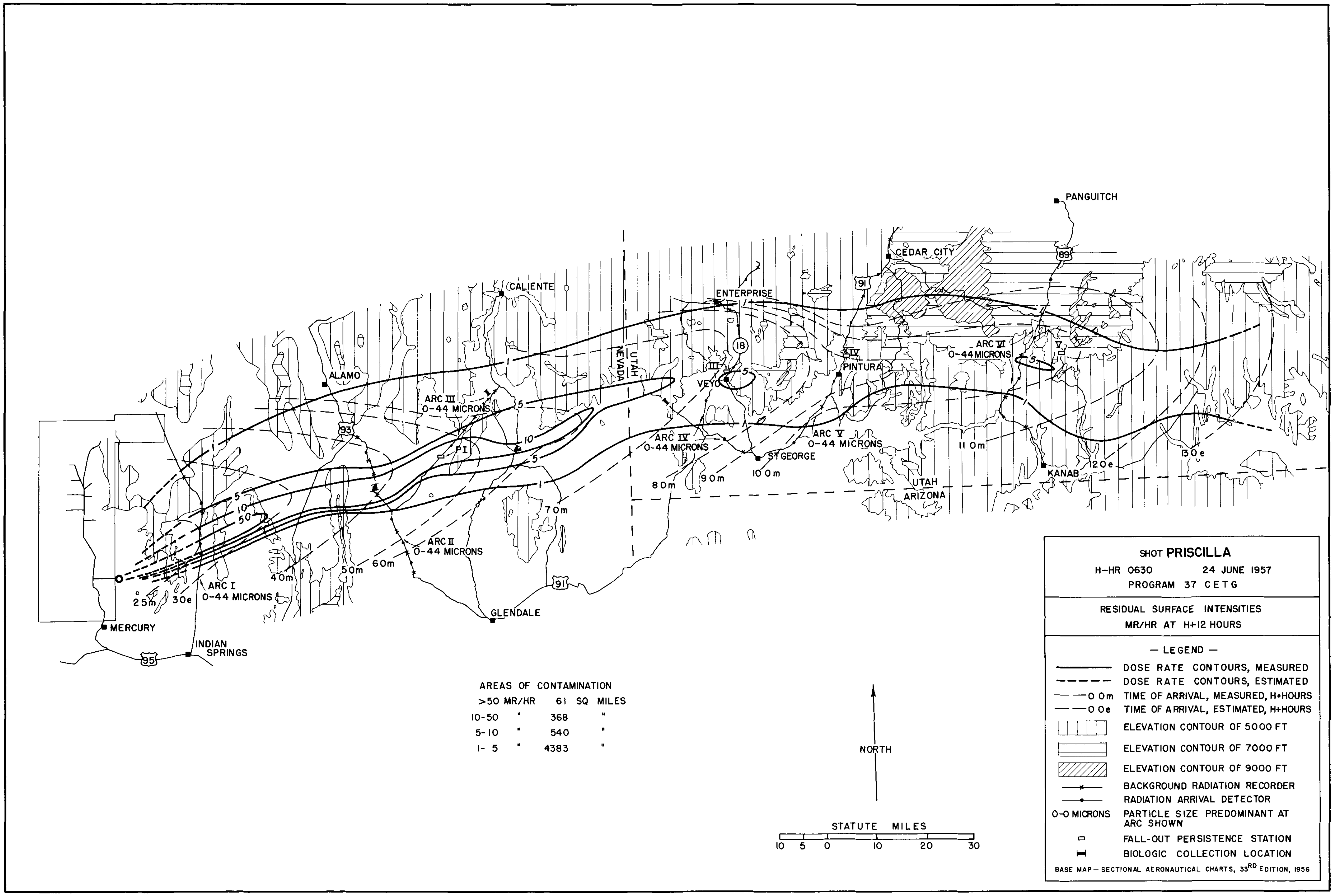


FIGURE 2.3 Priscilla Fallout Pattern

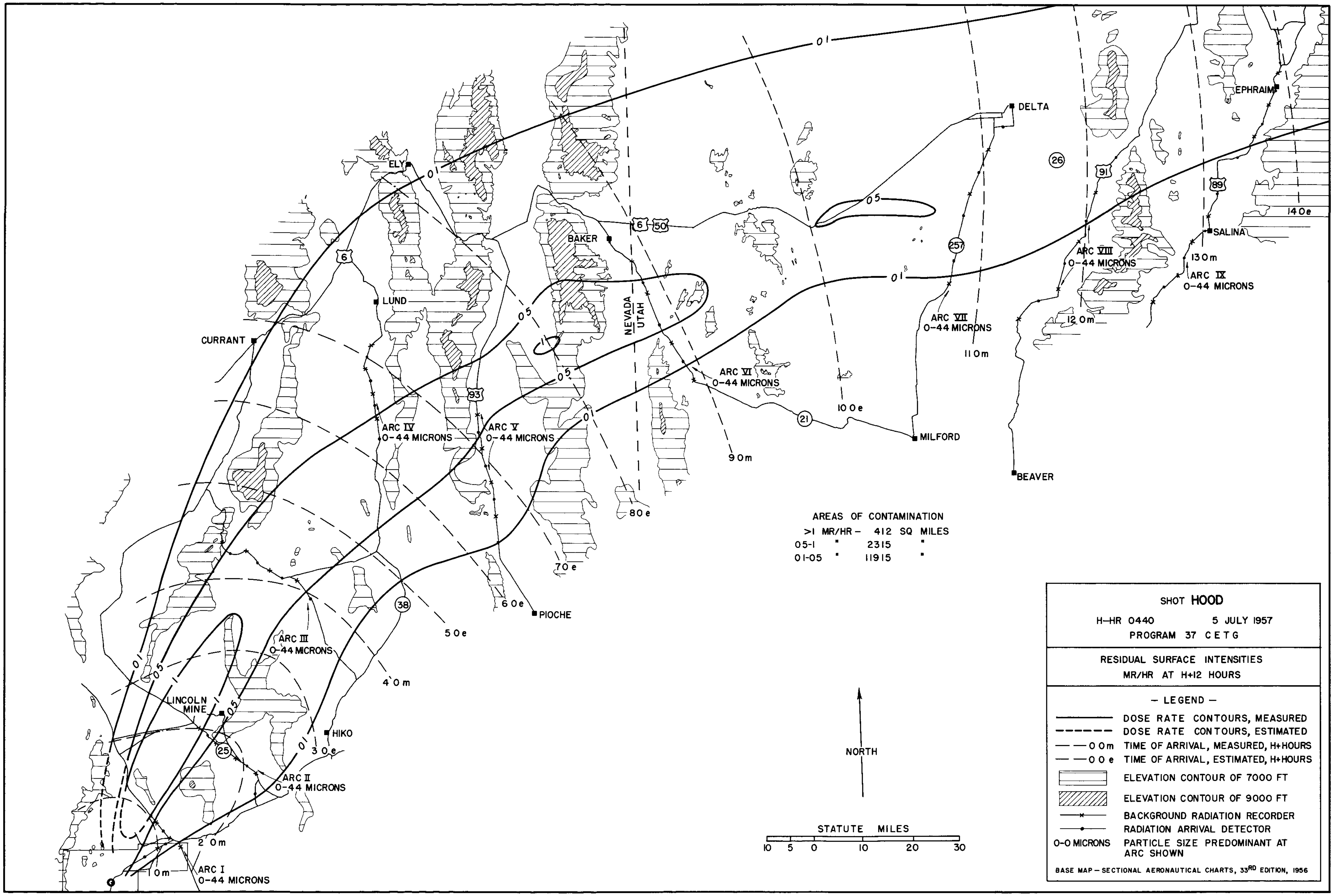


FIGURE 2.4 Hood Fallout Pattern

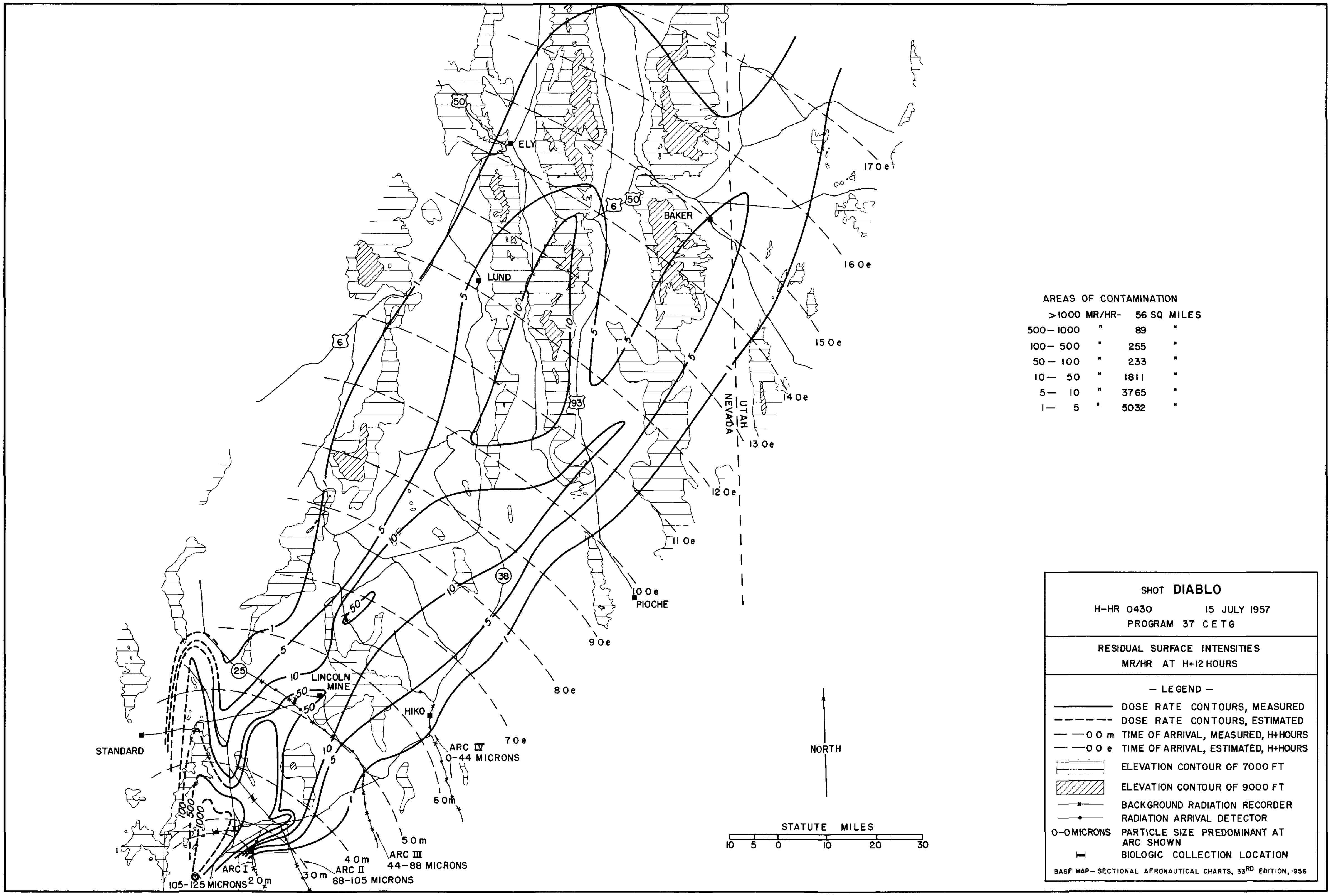


FIGURE 2.5 Diablo Fallout Pattern

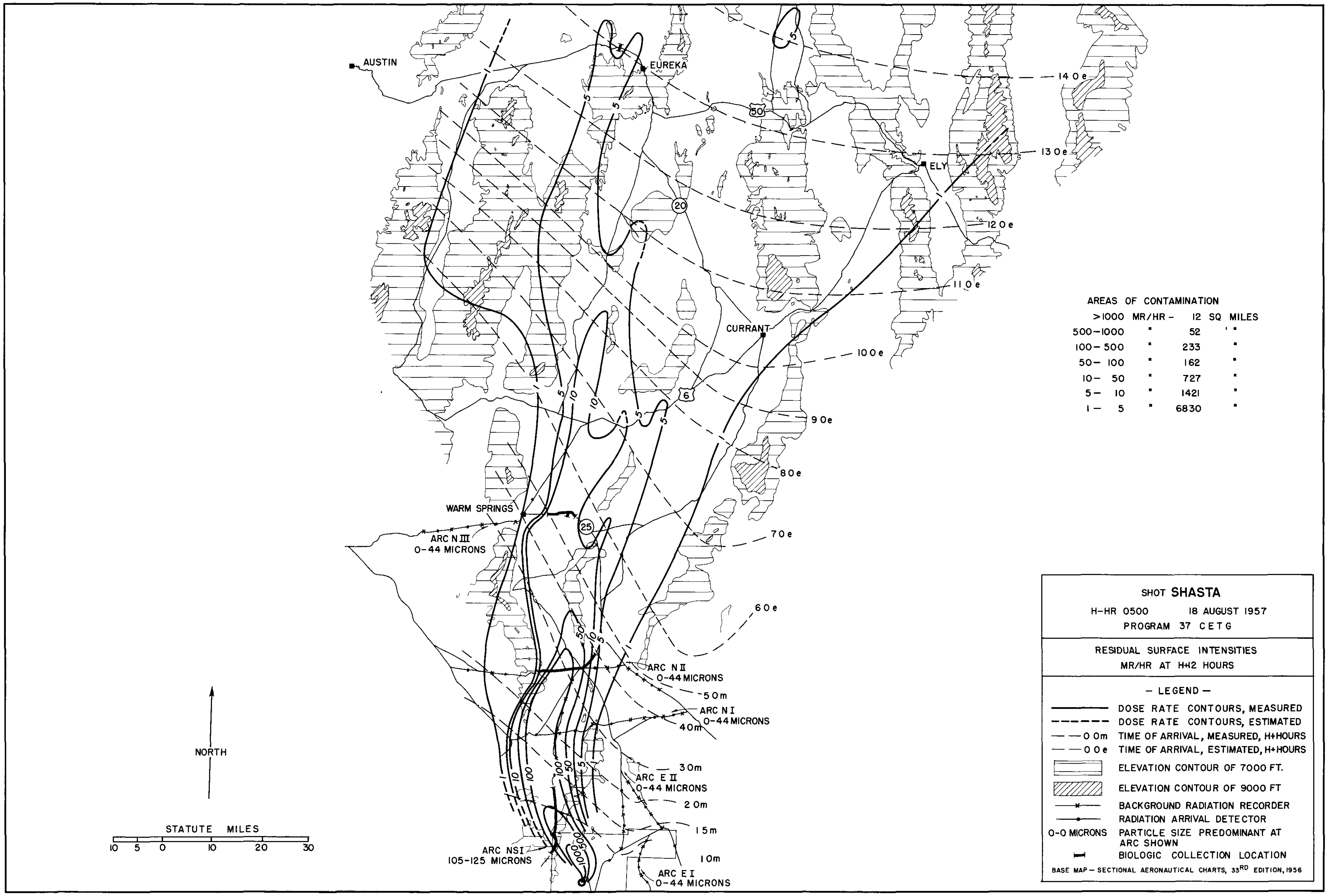
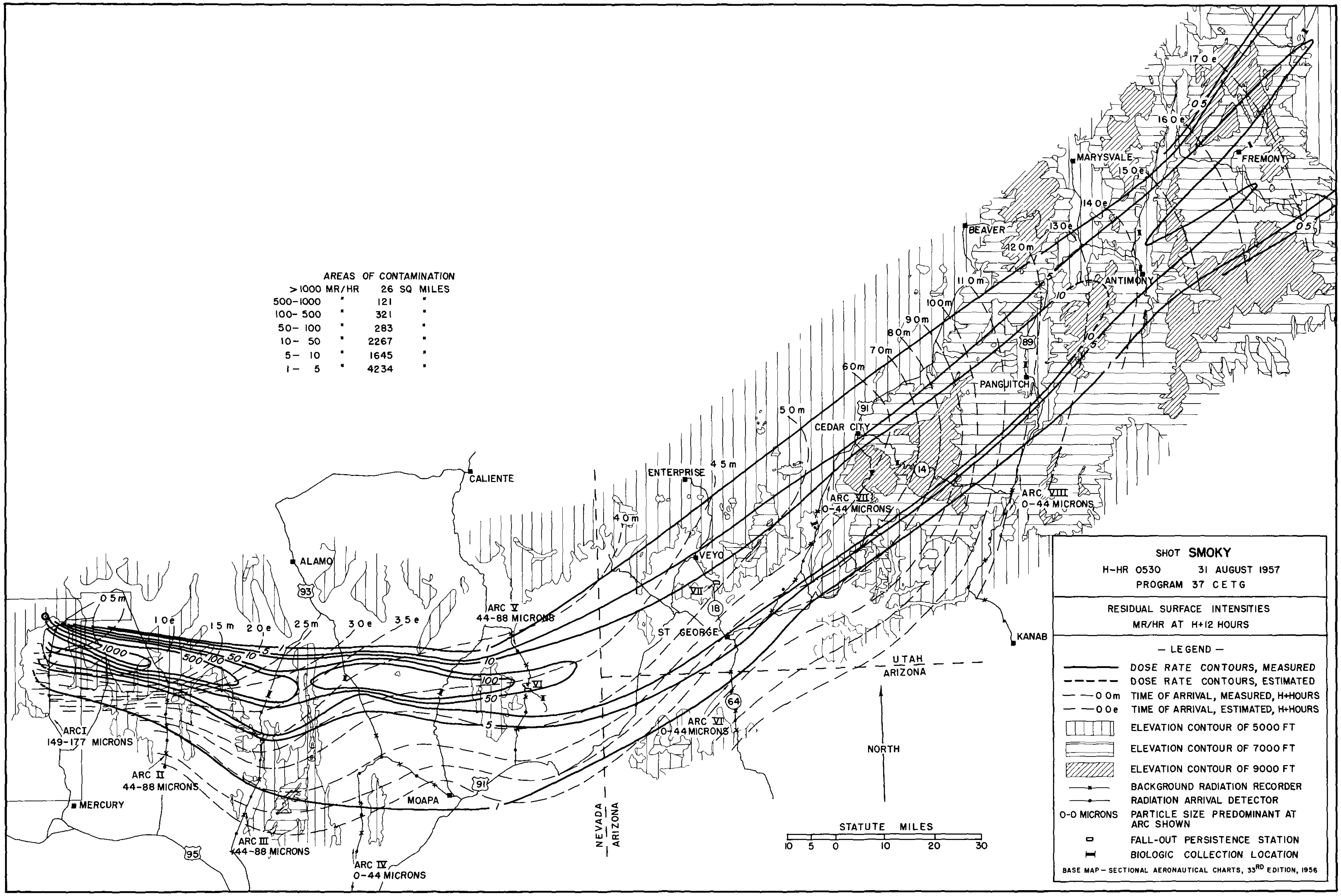


FIGURE 2.6 Shasta Fallout Pattern



AREAS OF CONTAMINATION

>1000 MR/HR	26	SQ MILES
500-1000 "	121	"
100- 500 "	321	"
50- 100 "	283	"
10- 50 "	2267	"
5- 10 "	1645	"
1- 5 "	4234	"

FIGURE 2.7a Smoky Fallout Pattern

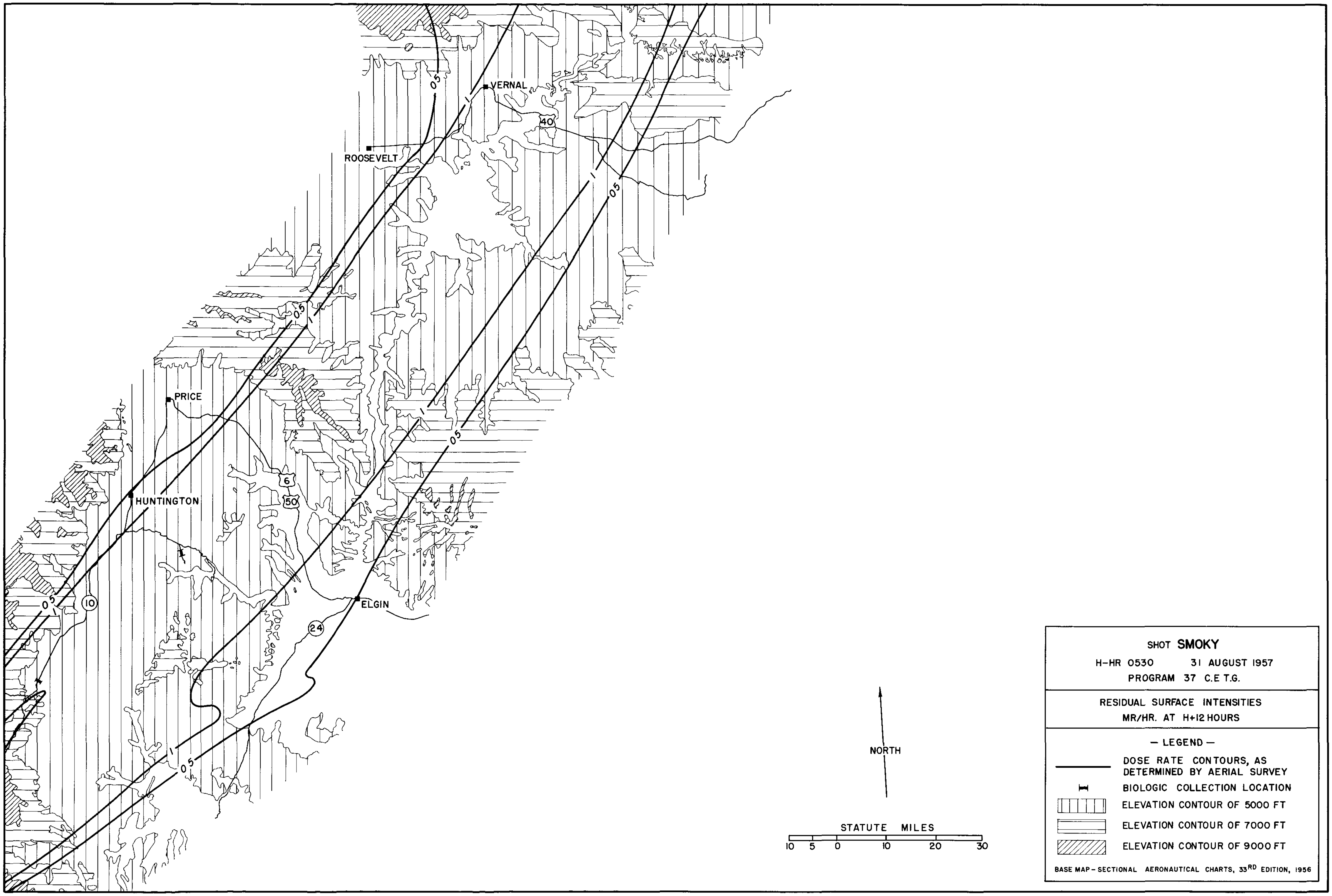


FIGURE 2.7b Smoky Fallout Pattern

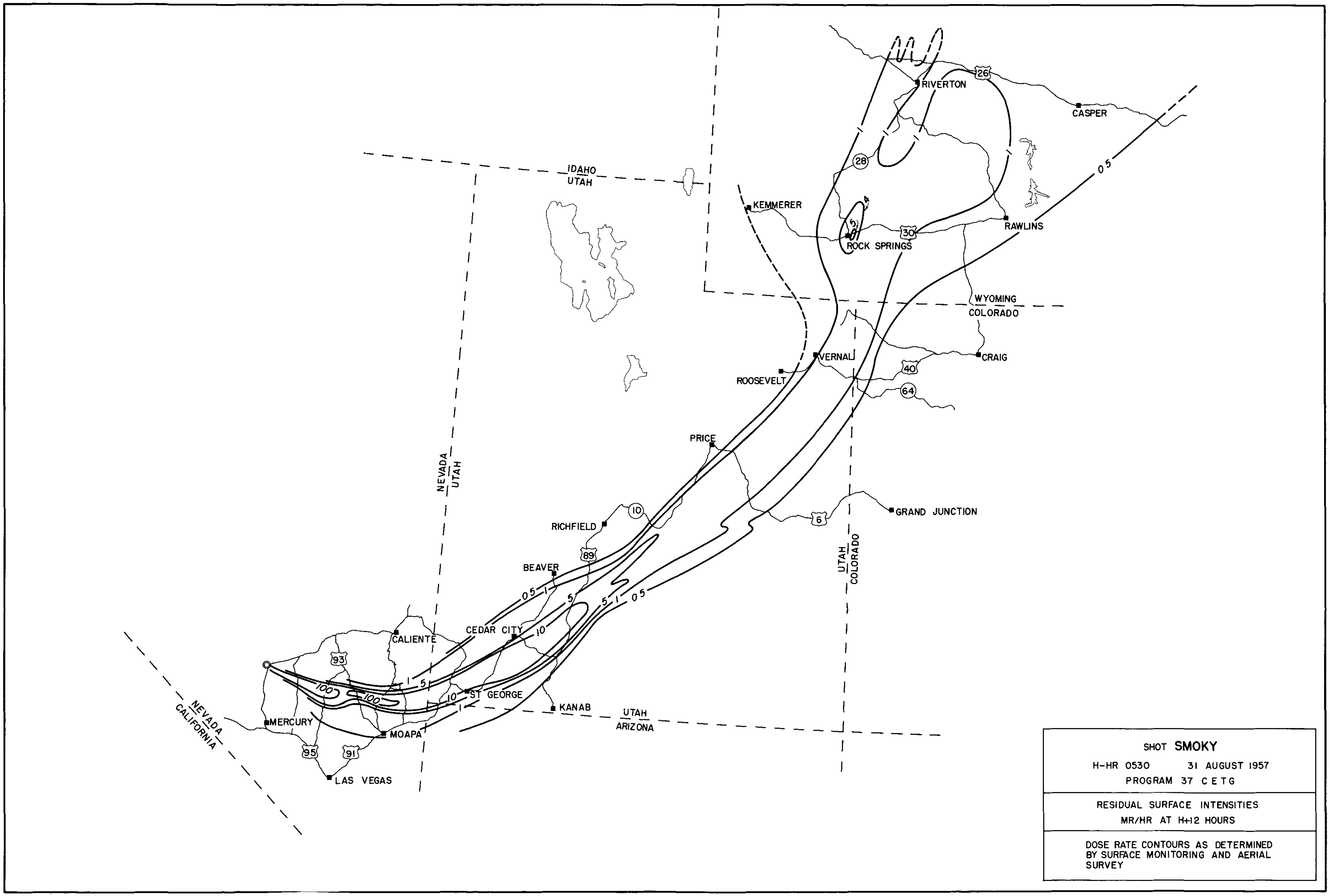


FIGURE 2.8 Smoky Extended Fallout Pattern

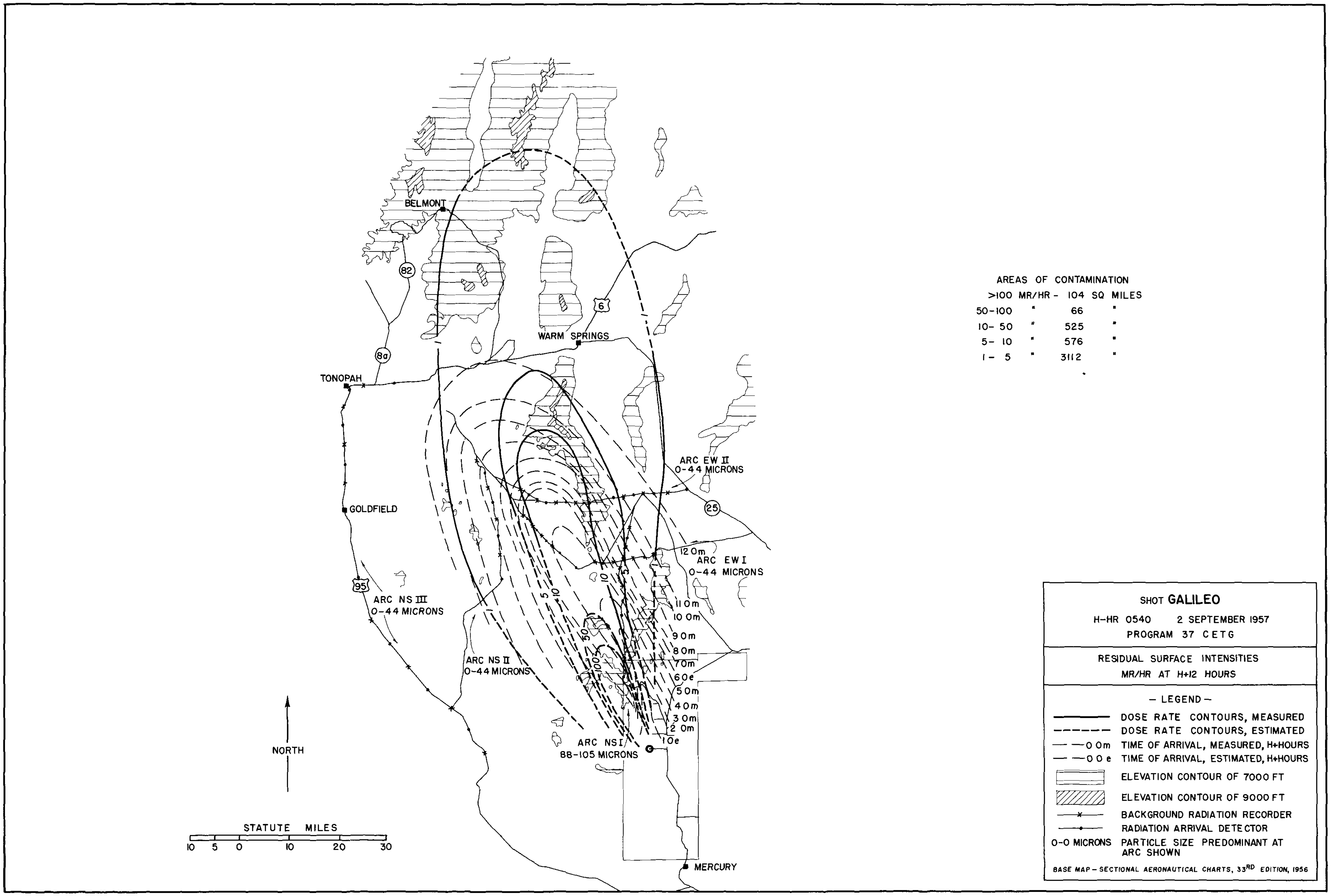


FIGURE 2.9 Galileo Fallout Pattern

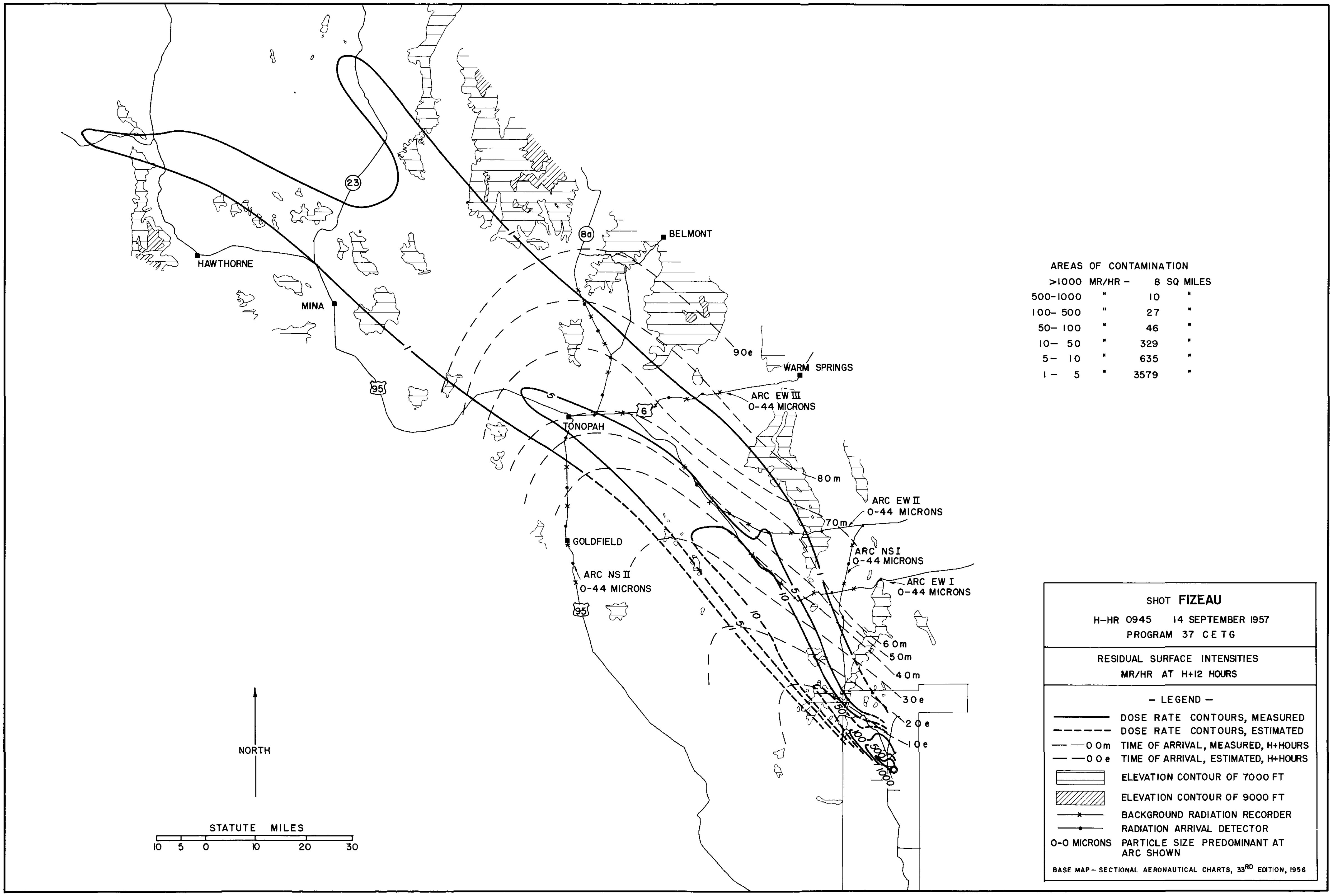


FIGURE 2.10 Fizeau Fallout Pattern

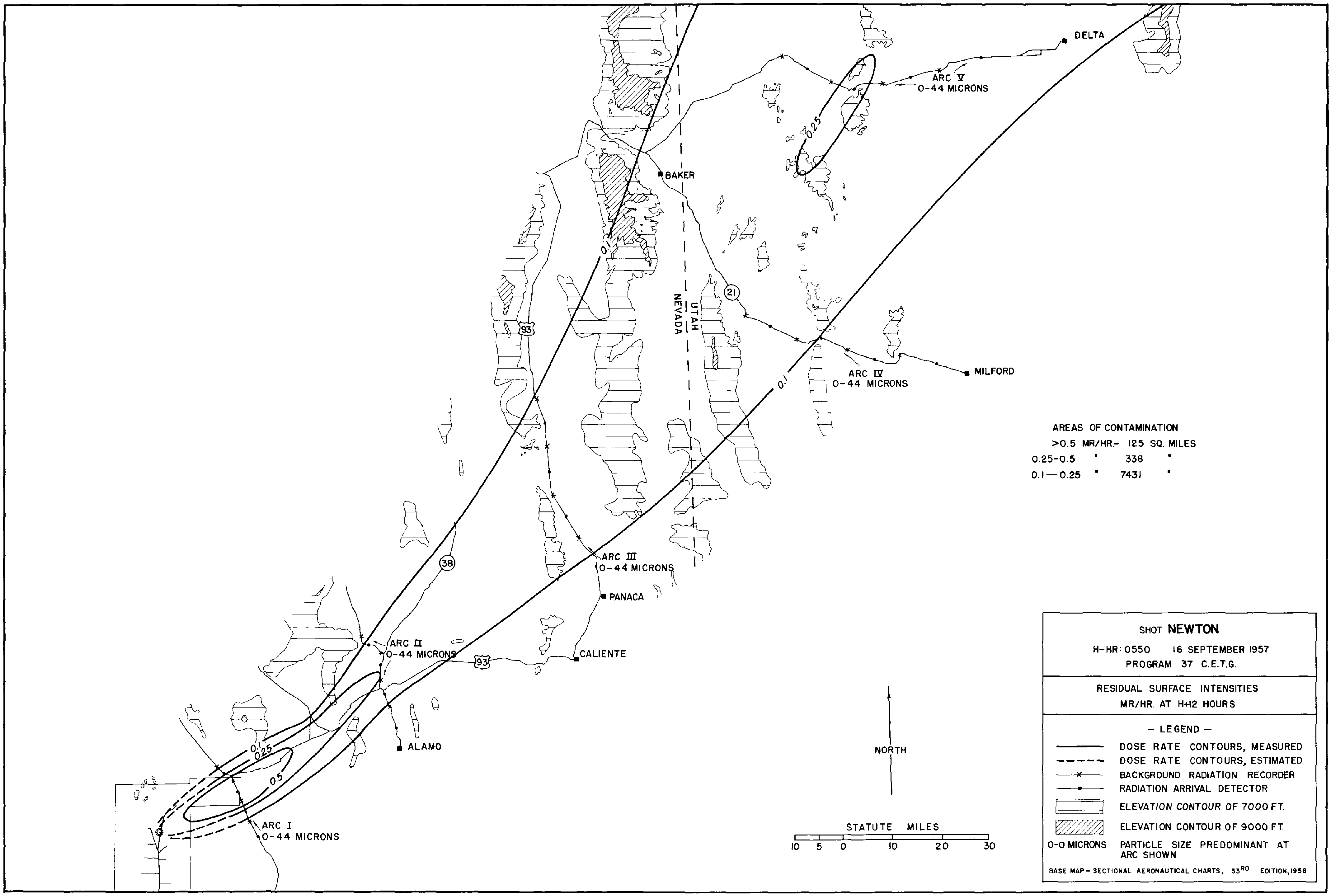


FIGURE 2.11 Newton Fallout Pattern

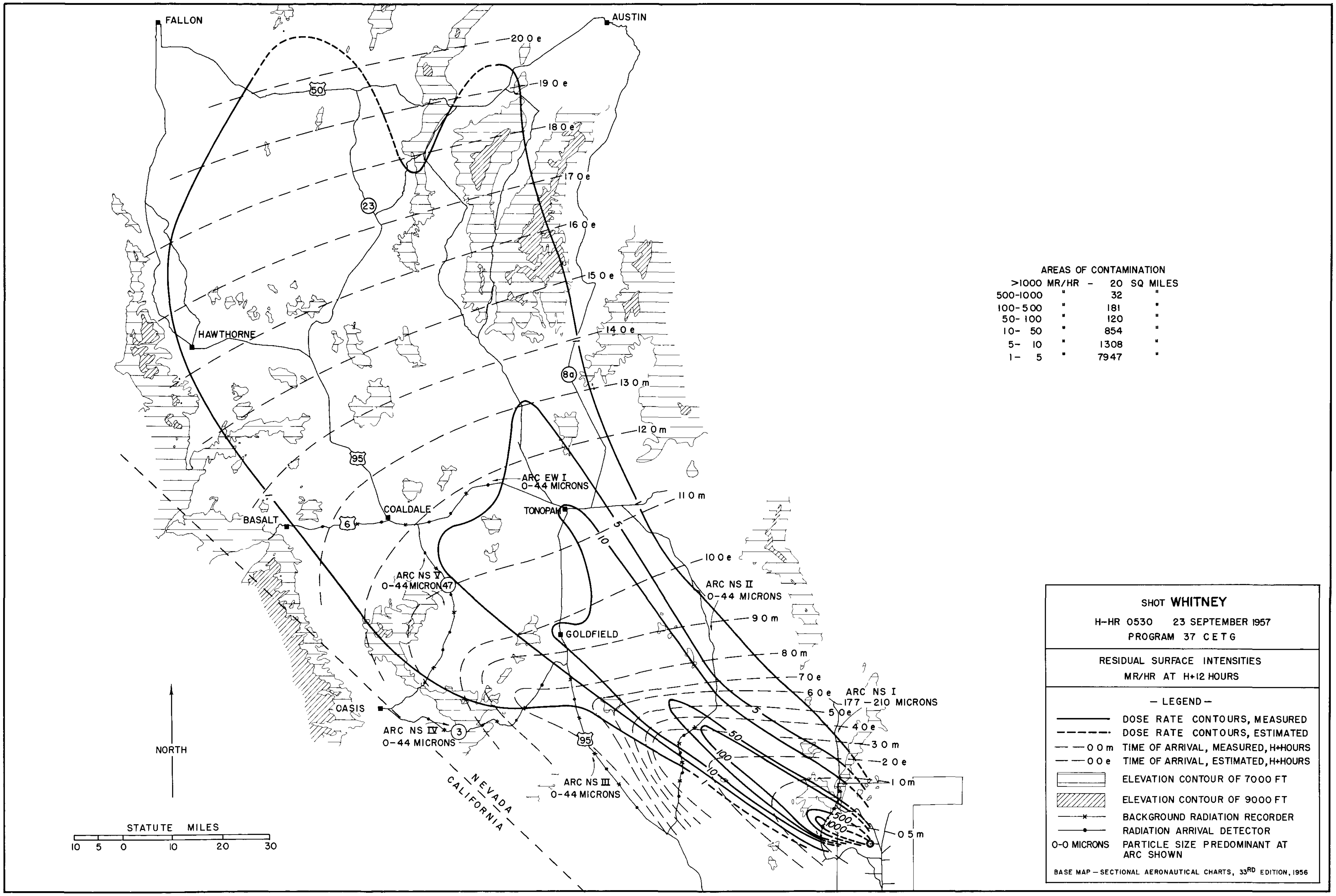


FIGURE 2.12 Whitney Fallout Pattern

2.3.2 Fallout Arrival Time and Duration

A rise of 2 mr/hr above background was arbitrarily chosen as giving the time of fallout arrival. Arrival times, both measured and estimated, are entered on the fallout pattern maps.

While the duration of fallout at individual locations is a function of a number of variables, e.g., initial particle size spectrum, particle size distribution within the cloud, vertical cloud shear, cloud height, a general relationship of fallout duration as a function of initial time-of-arrival was observed from recording gamma-radiation monitors (PRAM; see Appendix A for description). This relationship is illustrated in Figure 2.13 where data derived from six tower and three balloon mounted shots are presented. The regression curve indicates that the interval between initial and maximum activity increased from approximately 25 minutes at an initial fallout time of H + 1 hour to approximately 5 hours at fallout time of H + 12 hours. The number of observations employed in this study lends credence to the 1.4 constant especially in the time range H + 1 to H + 8 hours.

Examples of radiation intensity curves resulting from short and very long fallout duration are illustrated in Figure 2.14. Both curves were obtained at locations approximately 50 miles from ground zero but under quite different conditions of cloud velocity and shear. The long duration curve demonstrates discontinuity in fallout which is probably associated with deposition from different cloud strata. The declining portions of the curves do not reflect additional detectable fallout levels after reaching the maximum intensity in either case. No quantitative data were obtained on the continuance of the fallout process after the peak in intensity. A few recorder traces indicate, however, that the time period between the peak intensity and the end of the fallout process might be greater than the period between initial fallout and peak intensity. Similar data from the Teapot Series (Reference 1) indicate that anomalies observed during that study were not due to a redistribution of the original fallout material.

Analysis of the time-intensity data from the gamma-recording monitors aided in the determination of both the gamma decay rate and gamma dose (Chapter 4).

2.3.3 Ratio of Beta Activity Per Unit Area to Dose Rate

Gamma dose readings were obtained at time of recovery (H + 24 to 30 hours) of the stations. The ratio of beta activity per sq ft to dose rate (μc/sq ft:mr/hr) at H + 12 hours was determined from available data. The ratios served to augment and evaluate dose rate or activity per unit area values, particularly when previous fallout contamination was suspected. Table 2.3 shows the average ratio for each arc across the fallout patterns from ten shots at different distances from ground zero.

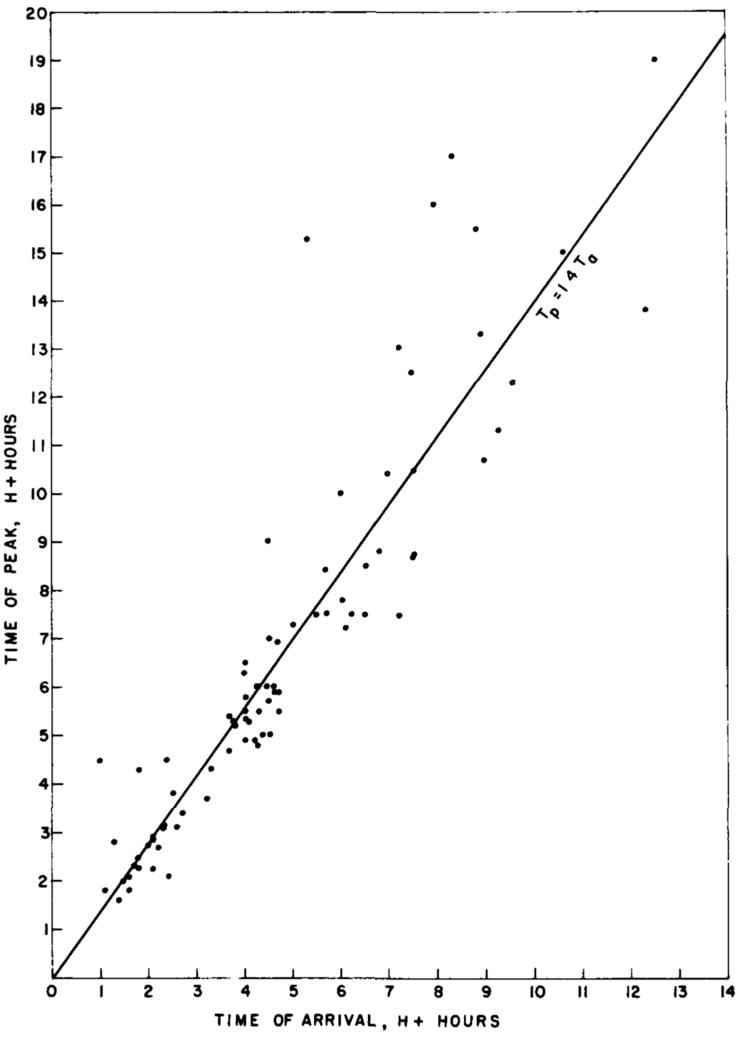


FIGURE 2.13 Relationship of Time of Peak Activity as a Function of Time-of-Arrival of Fallout or Radiation.

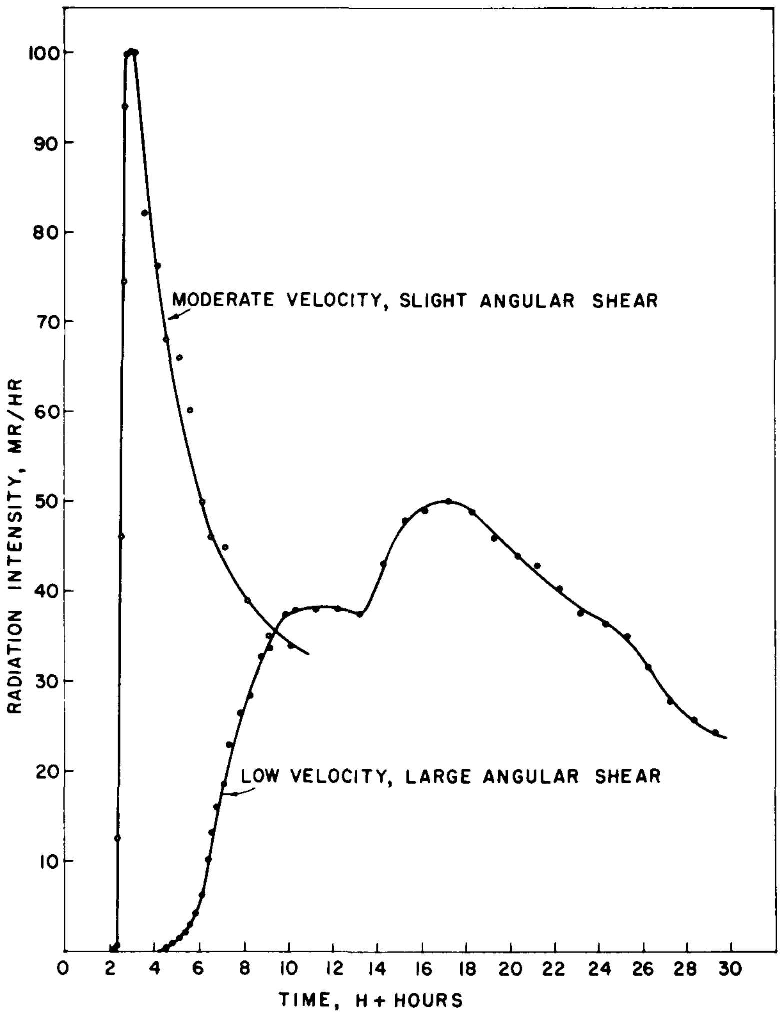


FIGURE 2.14 Relationship of Fallout Duration as a Function of Time-of-Arrival Radiation.

TABLE 2 3 Ratio of Beta Activity per sq ft to Dose Rate

Shot	Location	Average Distance from G Z , Miles	Number of Stations	Beta μc/sq ft mr/hr, H + 12 hr
Boltzmann	Arc I	35	15	7 34 ± 5 36
	Arc II	48	16	11 67 ± 3 61
	Arc III	78	12	9 57 ± 4 28
	Average		43	9 58 ± 4 75
Priscilla	Arc I	18	20	1 86 ± 0 80
	Arc II	55	9	4 03 ± 0 69
	Arc III	69	24	1 77 ± 0 38
	Arc IV	129	13	2 89 ± 0 58
	Arc V	154	6	5 74 ± 0 92
	Arc VI	188	5	2 32 ± 0 61
	Average		77	2 59 ± 1 33
Hood	Arc I	14	8	0 51 ± 0 97
	Arc II	35	3	2 66 ± 1 24
	Arc III	71	5	1 56 ± 0 53
	Arc IV	104	3	2 59 ± 0 78
	Arc V	115	4	3 09 ± 1 98
	Arc VI	160	6	2 87 ± 0 73
	Arc VII	220	2	2 94 ± 0 02
	Arc VIII	230	2	4 13 ± 0 73
	Arc IX	280	4	1 31 ± 0 60
	Average		37	2 07 ± 0 41
Diablo	Arc I	15	4	13 03 ± 1 94
	Arc II	20	6	8 87 ± 3 09
	Arc III	40	28	8 45 ± 2 86
	Arc IV	62	14	11 02 ± 4 57
	Average		52	9 54 ± 3 62
Shasta	Arc NC I	18	19	14 45 ± 3 89
	Arc N I	32	15	10 92 ± 2 28
	Arc N II	44	38	10 80 ± 5 12
	Arc N III	76	10	15 64 ± 5 53
	Average		82	12 26 ± 4 85
Smoky	Arc I	10	12	8 69 ± 2 43
	Arc II	26	20	14 16 ± 6 18
	Arc III	50	19	10 11 ± 3 75
	Arc IV	70	32	12 05 ± 4 86
	Arc V	100	20	12 47 ± 3 41
	Arc VII	155	19	9 10 ± 2 34
	Arc VIII	200	5	9 08 ± 2 60
	Average		127	11 28 ± 4 51
Galileo	Arc NS I	16	36	7 64 ± 4 10
	Arc NS II	48	5	6 29 ± 1 31
	Arc EW I	45	37	14 79 ± 5 98
	Arc EW II	52	39	8 39 ± 3 26
	Average		117	10 09 ± 5 50
Fizeau	Arc NS I	30	8	5 40 ± 3 65
	Arc NS II	95	24	8 43 ± 2 77
	Arc EW I	50	14	9 23 ± 2 19
	Arc EW II	60	16	10 68 ± 3 87
	Arc EW III	95	13	9 26 ± 1 80
	Average		75	8 88 ± 3 19
Newton	Arc I	18	13	1 43 ± 0 96
	Arc II	55	20	1 48 ± 0 56
	Arc V	210	18	2 26 ± 0 83
	Average		51	1 74 ± 0 85
Whitney	Arc NS I	10	12	11 72 ± 6 23
	Arc NS II	43	13	10 66 ± 2 03
	Arc NS III	60	8	11 21 ± 2 57
	Arc NS IV	75	11	13 17 ± 3 01
	Arc NS V	96	20	16 26 ± 4 62
	Arc EW I	110	19	12 65 ± 4 67
	Average		83	13 00 ± 4 61

There is no apparent correlation between these ratios and time-of-arrival, distance from ground zero, or mean particle size. Balloon mounted detonations, however, appear to yield lower values, ratios of 1.5 to 2.5, than do tower mounted shot ratios of 8.9 to 13.0. This is at variance with data presented in Chapter 4 which indicate that laboratory determined beta to gamma ratios from granular collector samples were generally greater for balloon mounted shots than for tower mounted shots. The significance of these differences is obscure.

2.4 DISCUSSION

2.4.1 Fallout Deposition in the NTS Environs from Tower and Balloon Shots

Interpretation of fallout levels with respect to yield and height of detonation of tower mounted devices is somewhat obscured by the differences in shielding materials and their masses with the cab and the tower mass. Table 2.4 lists the approximate weight of towers and cabs used for the detonations documented by this Program. Balloon detonation close-in fallout was consistently less than tower fallout due to (1) height of burst and, therefore, the degree of fireball interception of the ground surface and (2) lack of a massive support structure. For tower mounted shots, the low level of radiation from Shot Fizeau was consistent with relatively low yield and tower-cab mass. However, the fallout radiation level for Shot Boltzmann of similar yield to Shot Fizeau was high. The total cab and metal shielding mass for both shots was approximately the same. The difference was probably due to the addition of 12.5 tons of silica sand in the Boltzmann cab and the effective height of detonation was 425 ft because of the earth bunker immediately beneath the Boltzmann cab. With the exception of Shot Boltzmann, the higher fallout levels were associated with the heavily lead shielded cabs and the heavier towers (Diablo, Shasta, Smoky, and Whitney). A somewhat lower fallout level was associated with concrete shielding in the cab of Shot Galileo even though the tower weight was similar.

TABLE 2.4 Approximate Weights of Shot Towers and Cabs.

Shot	Tower Weight, Tons	Cab and Shielding, Tons
Boltzmann	< 25,000	< 50
Fizeau	< 25,000	< 50
Smoky	35,000 to 70,000	> 100
Galileo	25,000 to 50,000	> 100
Diablo	> 50,000	> 100
Shasta	> 50,000	> 100
Whitney	> 50,000	> 100

It has been reported (Reference 2) that available data from previous tower mounted shots at NTS are not adequate to determine the quantitative effects of the amount of shielding incorporated in fallout debris on fallout levels but that heavier towers do contribute to increases in fallout deposition.

Observations of the remains of towers and shielding material after detonation at several ground zeros indicate that large masses of material are not vaporized. Observation of the residue of the Smoky tower indicated that a very significant portion of that tower remained including the upper 200 feet of steel. Another example similar to Shot Smoky was Shot Apple II, Teapot Series. Even though the total yield of Shot Apple II was about 32 kt, the floor of the cab and the main tower support columns remained intact. The results of the Shot Fizeau tower melt studies (Reference 3) show that about 85 percent of tower material was accounted for after the detonation and that only the upper 50 feet of tower was vaporized. No melting occurred beyond 175 feet from the top of the tower although the fireball theoretically engulfed more than 400 feet of the tower.

These observations indicate that before a realistic approach can be made in formulating reliable prediction models, information should be obtained as to how much material is actually consumed in the formation of fallout particles.

2.5 SUMMARY

1. Dose rates and time of arrival of fallout or radiation resulting from Shots Boltzmann, Wilson, Priscilla, Hood, Diablo, Shasta, Smoky, Galileo, Fizeau, Newton, and Whitney were measured and are reported in terms of isodose-rate and isofallout-time contour maps.
2. Radiation hot spots were observed in fallout patterns of both tower and balloon mounted shots. These are probably caused by the atmospheric turbulence present over the mountain ridges.
3. A relationship between time of fallout arrival (T_a) to time of peak activity (T_P) was derived, $T_P = 1.4\ T_a$.
4. Ratios of beta activity (μc/sq ft) to dose rate (mr/hr) at H + 12 hours ranged from 8.9 to 13.0 for tower mounted shots and 1.5 to 2.5 for balloon mounted shots. No explanation is offered for the differences.
5. The levels of fallout from tower mounted shots were greatly influenced by mass and nature of tower and cab materials.

REFERENCES

1. L. Baurmash and others, "Distribution and Characterization of Fallout and Airborne Activity from 10 to 160 Miles from Ground Zero, Spring 1955", Project 37.2 (CETO), Operation Teapot, WT-1178, November 1958, Atomic Energy Project, School of Medicine, University of California, Los Angeles, California, Unclassified.

2. J. W. Reed; "Fallout Yield Prediction for Tower Shots"; Report No. SCTM 108-58 (51), March 1958; Sandia Corporation, Albuquerque, New Mexico; Classification, Secret.

3. W. K. Dolen and A. D. Thornborough; "Fizeau Tower Melt Studies as Related to Fallout Prediction"; Report No. SC-4185, April 1958; Sandia Corporation, Albuquerque, New Mexico; Classification, Secret.

CHAPTER 3

ACTIVITY PER UNIT AREA AND PARTICLE SIZE DISTRIBUTION IN FALLOUT PATTERNS

3.1 INTRODUCTION

Further characterization of the fallout pattern is made by determining the distribution of the radioactive sources in it. Through particle size analysis of samples collected at selected locations in a fallout pattern, the distribution of radioactive materials can be determined according to particle size fractions along with the radionuclide content. These data contribute to the understanding of biological availability of the radioactive material at various locations in the fallout pattern and, in particular, with respect to distance from ground zero. In addition, the data provide some indication of fractionation within the cloud through study of particle trajectories.

3.2 PROCEDURE

The activity (microcuries) per square foot from fallout debris was determined from samples collected by large area (4.73 sq ft) granular collectors (GC) The GC consisted of a layer of polyethylene pellets spread uniformly over a known surface area of a metal tray covered with plastic film For each shot studied, one hundred to three hundred collectors were placed at ground level in the field prior to the arrival of fallout and were exposed until station recovery on D + 1 day They were then collected and returned to the Mercury Laboratory for processing and assay. See Appendix A for details (Section A 3.1).

It was anticipated that the number of detonations scheduled for this test series would result in fallout patterns that would overlap one another. Also, the acceptable sectors through which fallout could be deposited were the same sectors in which fallout had occurred from detonations of previous test series. Therefore, it was necessary to develop a new technique of collection to avoid cross-contamination of samples. In addition, the method of processing these samples required improvement in order to determine more reliably the activity per unit area, the particle size distribution and other characteristics. The GC was developed and used by this Program.

On four shots–Boltzmann, Diablo, Shasta, and Smoky–sixty-five of the established collector stations were also equipped with gummed paper collectors (GPC). In addition, on Shot Boltzmann, resin coated plates (RCP), the LASL Model, were added to twenty stations at which GPC's were located. Also, a soil sample, one square foot in area and one inch deep, was taken at these multiple collector stations. These various samples permitted comparison of the relative collection efficiencies of the several media. The GPC had been used by the Health and Safety Laboratory (HASL) New York Operations, USAEC, in earlier studies. The RCP was developed by the H-Division, Los Alamos Scientific Laboratory (LASL), and was used by various organizations.

All radioassay data were referred to the common time, H + 12 hours, using the composite Plumbbob beta decay curves presented in Figure 4.11.

3.3 RESULTS AND DISCUSSION

Activity per square foot and particle size distribution measurements were made on fallout samples from seven tower mounted and three balloon mounted detonations. Data are presented on selected shots that illustrate the results obtained: Shots Boltzmann, Priscilla, and Smoky provided data shown in Appendix C. Particular attention was given to the less than 44 micron fraction because of its significance to fallout prediction models and to assessment of biotic availability.

Data and their evaluation are presented which establish the basis for using the granular collector as a method for obtaining reliable samples for the measurement of activity per square foot and particle size distribution of fallout material.

3.3.1 Comparison of Collectors

3.3.1.1 Gummed Paper and Resin Plate Versus Granular Collector

The fallout collection efficiency of gummed paper was compared to that of the GC at 65 locations contaminated by fallout from Shots Boltzmann, Diablo, Shasta, and Smoky. Distances from ground zero varied from approximately 16 to 80 miles, and a wide variety of lateral distances from the midline was represented. Also, the collection efficiency of resin plates was compared to that of the GC at 20 locations within the Boltzmann pattern at distances ranging from approximately 35 to 80 miles from ground zero.

The results of the comparisons are summarized in Figure 3.1 as histograms depicting the frequency of observed ratios of GPC/GC or RCP/GC beta μc/sq ft (at H + 12 hours). The GPC and RCP radioactivity value at each location was the mean activity of twelve 0.5 sq ft and twelve 0.25 sq ft samples, respectively, and that of the GC was the mean activity of two 4.73 sq ft samples.

A wide range of GPC/GC activity ratios was observed (from 0.005 to 2.86) with a mean value of 1.11 for 65 observations. The modal or most typical ratio was the range of 1.25 to 1.50 which represented 20 percent of the cases. Attempts to correlate ratios with total activity levels or particle size distributions were generally unsuccessful with the exception that the extremely low ratios in the range of 0 to 0.25 (15 percent of the cases) tended to be associated with low total activity values, i.e., less than 5 μc/sq ft. While possibly indicating a higher collection efficiency by the GC for small particle sizes, this relationship was not consistent. Variability in fallout deposition, as described below, provides a more satisfactory explanation of the range of ratios observed.

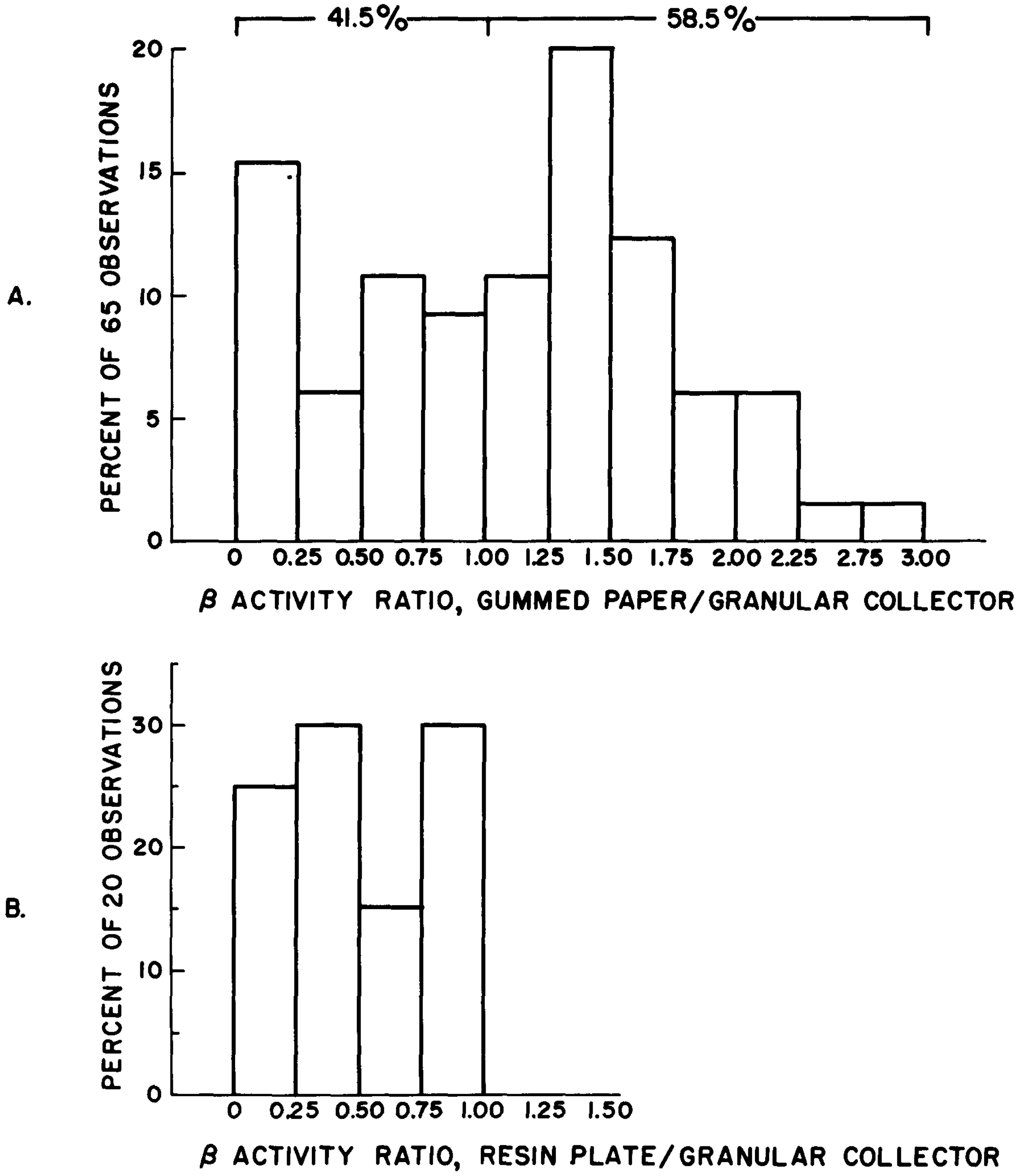


FIGURE 3.1 Distribution of Ratios of Beta μc/sq ft Values of (A) Gummed Paper and (B) Resin Plate Collectors to Granular Collector Values at Identical Sampling Locations.

Fewer comparisons of RCP and GC beta radioactivity values were performed; however, RCP values were consistently less than those of corresponding GC's at 20 locations in the Boltzmann fallout pattern.

3.3.1.2 Replication Variability

Coefficient of variation values descriptive of the variation among 12 GPC or RCP samples collected at different locations in Boltzmann, Diablo, Shasta, and Smoky, fallout areas and four, 4.73 sq ft GC samples collected in the Smoky fallout pattern were determined. These values, plotted as a function of H + 12 hour beta μc/ft sq ft levels determined by the GC's, and regression curves constructed on the basis of the least squares method appear in Figures 3.2, 3.3, and 3.4 for GPC, RCP, and GC, respectively.

Both GPC and RCP curves indicate decreasing coefficients of variation with increasing fallout levels as would be anticipated where higher fallout levels reflect larger numbers of particles falling per unit area. Values of the coefficient of variation, derived from the regression curves over the fallout activity range of 1 to 1000 μc/sq ft at H + 12 hours, range from 30 to 8 percent for gummed papers and 45 to 22 percent for resin plates. The higher values for resin plates possibly reflect their smaller size, although the small number of resin plate cases precludes firm conclusions. In contrast to both GPC and RCP, GC coefficients do not demonstrate a detectable influence of fallout activity level over the fallout range of 1 to 1000 μc/sq ft where a value of 13 percent was determined. This generally lower coefficient value can be attributed to the larger unit areas involved, 4.73 sq ft as opposed to 0.5 or 0.25 sq ft in the cases of gummed paper and resin plates, respectively.

To further explore the effect of fallout level on variation of GC samples, approximately 200 sample locations in the Smoky fallout pattern were analyzed on the basis of duplicate 4.73 sq ft samples. The larger of the two fallout activity values was divided by the smaller to give ratios equal to or greater than one; the ratios were plotted as a function of the mean activity value and a regression line determined, Figure 3.5. Duplicate samples indicate an effect of level on variability, and regression line values range from 1.5 at 0.1 μc/sq ft to essentially 1.0 at 10,000 μc/sq ft. By the standard deviation approximation method of Dixon and Massey (Reference 1), duplicate sample ratios of the order of 1.5 would correspond to coefficient of variation values of approximately 35 percent. A ratio of 1.2 at a fallout level of 100 μc/sq ft would correspond to a coefficient of variation of approximately 16 percent. This compares favorably with coefficients of 28 percent for 12 resin plates, 13 percent for 12 gummed papers, and 13 percent for four 4.73 sq ft GC samples at the same fallout level.

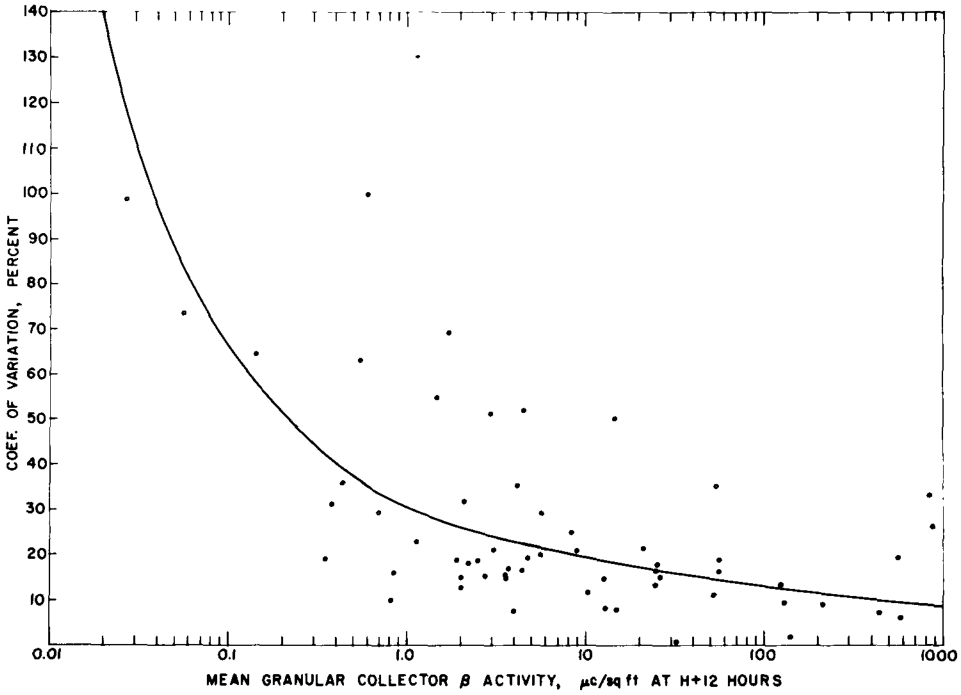


FIGURE 3.2 Effect of Fallout Level on Unit Area Activity Variation Among Twelve Gummed Paper Replicate Samples.

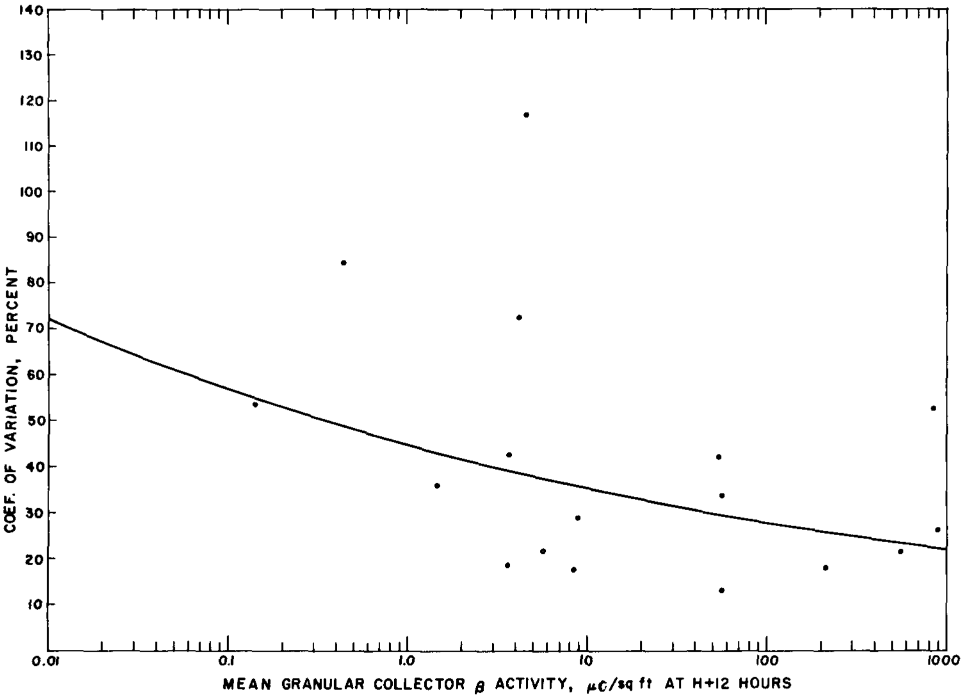


FIGURE 3.3 Effect of Fallout Level on Unit Area Activity Variation Among Twelve Resin Plate Replicate Samples.

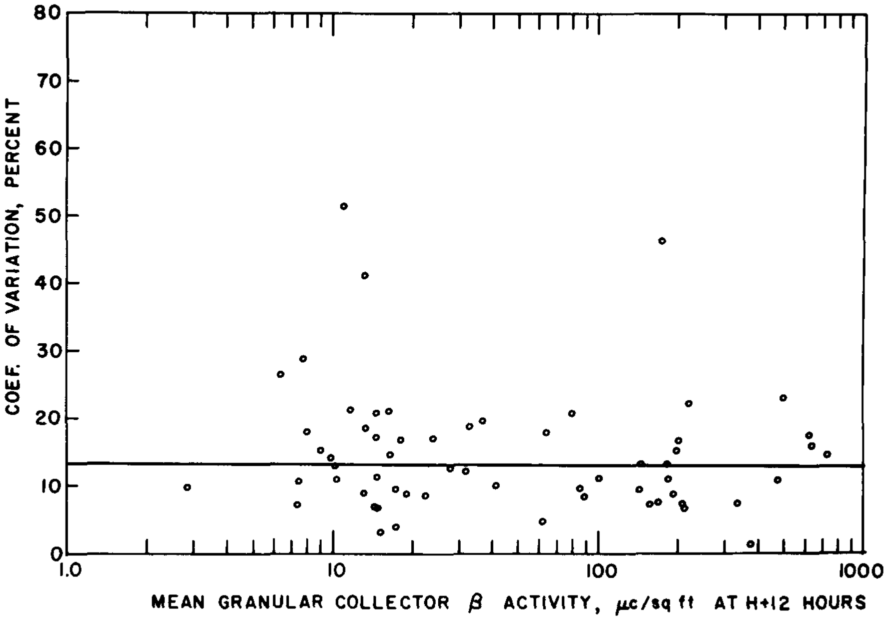


FIGURE 3.4 Effect of Fallout Level on Unit Area Activity Variation Among Four Granular Collector Replicate Samples.

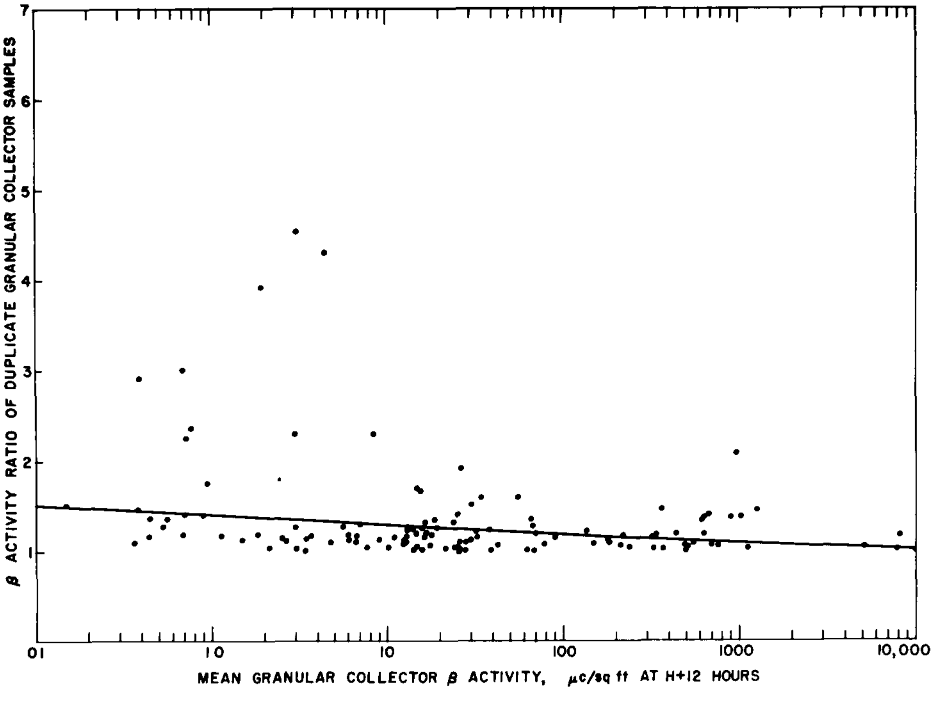


FIGURE 3.5 Effect of Fallout Level on Ratios of Duplicate 4.73 sq ft Granular Collector Samples.

3.3.1.3 Soil Sample Evaluation

One square foot, one inch deep soil samples were collected at various GC locations in the Boltzmann, Shasta, and Priscilla fallout patterns for comparison of total beta activity and particle size distributions.

The ratios of soil-to-GC beta activity values as of H + 12 hours are plotted in Figure 3.6 as a function of μc/sq ft at H + 12 hours values determined by duplicate 4.73 sq ft GC samples. With the exception of one sample, all Priscilla soil samples were higher than corresponding GC samples by factors in excess of two. Boltzmann and Shasta ratios are grouped around a value of one with the exception of two low-level (4 μc/sq ft) samples. The ratios generally indicate an increasing discrepancy with decreasing fallout level.

An analysis of sample locations and times of radioassay indicates a probable explanation for the observed discrepancies between the two types of sample. Soil samples are subject to error with respect to residual surface soil radioactivity due to fallout from previous detonations; the deduction of subsoil radioactivity values only eliminates the error due to naturally-occurring radioactive isotopes. However, the error due to residual activity is large by comparison. This error becomes greater at later times after shot as the long half-life radionuclides become a greater percentage of the total. In contrast to previous test series, where the soil sample represented the primary sample for fallout measurement, soil sample processing during the Plumbbob Series was delayed in favor of GC processing. In general, soil samples were radioassayed at times ranging from one to several months after the respective detonations. As an example of the effect of delayed radioassay, a sample having a beta activity level of ten μc/sq ft at H + 12 hours would have a level of approximately 0.02 μc/sq ft three months after shot. A residual contamination level of 0.02 μc/sq ft would produce an H + 12 hour extrapolated value which would be high by a factor of two.

Soil samples from the Priscilla pattern were subject to error resulting from delayed radioassay of initially low radioactivity values and residual contamination from the Shot Met (Teapot Series) pattern with which it coincided to the distance at which fallout occurred at approximately H + 6 hours. At the time of the Priscilla soil radioassay, maximum residual beta activity levels of the order of 0.6 μc/sq ft could be attributed to Shot Met on the basis of published fallout level values (Reference 2). Various ratios of residual contamination (from all sources) and Priscilla contamination could account for the range of high soil-to-GC beta activity ratios observed in Figure 3.6.

Boltzmann and Shasta soil samples generally indicated closer agreement with GC beta activity values than those from Shot Priscilla. At higher fallout activity levels

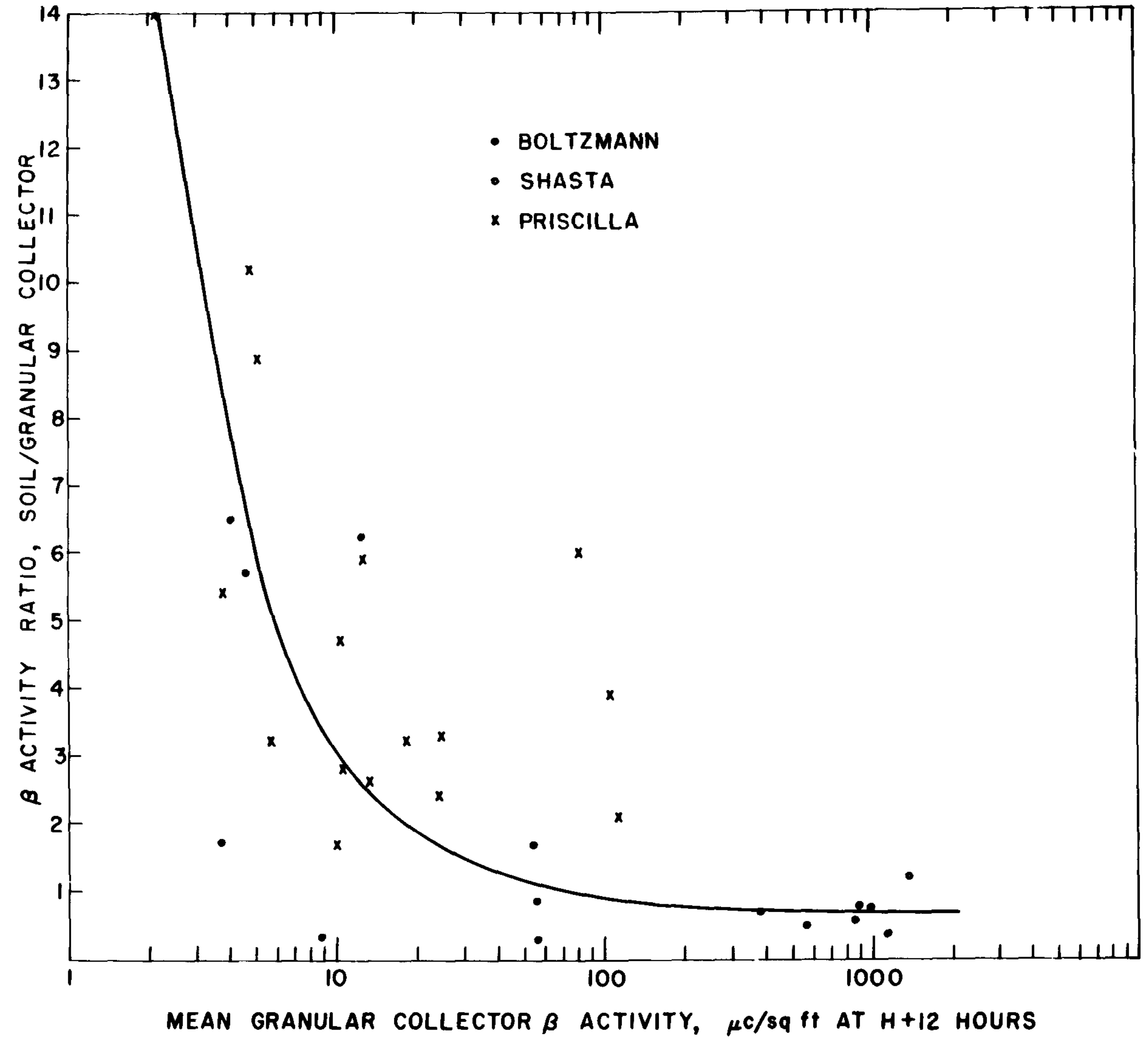


FIGURE 3. 6 Effect of Fallout Level on Ratios of Beta μc/sq ft Values of Soil Samples to Granular Collector Values at Identical Sampling Locations.

(< 300 μc/sq ft), the effect of residual contamination was probably negligible, and the degree of variation around a ratio of one could be attributed to sample variations associated with one square foot samples.

An analysis was made of the relative size distributions obtained by soil samples and granular collectors at corresponding locations in tower and balloon shot fallout patterns. Typical results appear in Figure 3.7 where particle size distributions for Boltzmann samples collected 47 miles and Priscilla samples collected 196 miles from ground zero are presented as cumulative percent curves.

Both pairs of curves indicate entrapment of smaller fallout particles by soil material of larger particle size. In the case of Priscilla samples where the percentage of less than 44 micron fallout was larger, the fine material was distributed somewhat uniformly over the entire particle size range. In the case of the Boltzmann samples, the distribution of fine material was masked by variations in the distribution of larger particle sizes representing the majority of the total radioactivity. In both cases, more than one-half of the less than 44 micron fallout material in the soil samples was associated with particle sizes larger than 44 microns.

3.3.2 Particle Size Distributions at Different Distances from Ground Zero

Sampling by GC's was sufficiently complete across the patterns on four shots to determine the total fallout particle size distribution at various distances from ground zero. The activity of each particle size range was integrated across each arc and the total particle size distribution determined on the basis of the integrated values. The total particle size distributions of Shots Boltzmann, Priscilla, Smoky, and Whitney at various distances from ground zero appear in Figures 3.8, 3.9, 3.10 and 3.11, respectively.

All four shots demonstrated increasing percentage contributions of the smaller sizes to total activity with increasing distance from ground zero. However, the balloon Shot Priscilla differed markedly from the tower shots with respect to the occurrence of the larger particle sizes; sizes greater than 44 microns in diameter comprised less than 50 percent of fallout at distances as close as 18 miles from ground zero in the case of Shot Priscilla.

The occurrence of significant percentages of less than 44 micron fallout at relatively short distances from ground zero for both tower and balloon mounted shots is of particular interest since it cannot be predicted on the basis of free-fall expressions. In contrast, the percentages of the 44 through 88 micron fractions were generally minimal at such distances.

3.3.3 Total Particle Size Distributions in Fallout Patterns

Estimates of total particle size distributions within the limits of one mile from ground zero to the distances at which fallout arrived at H + 12 hours were obtained by

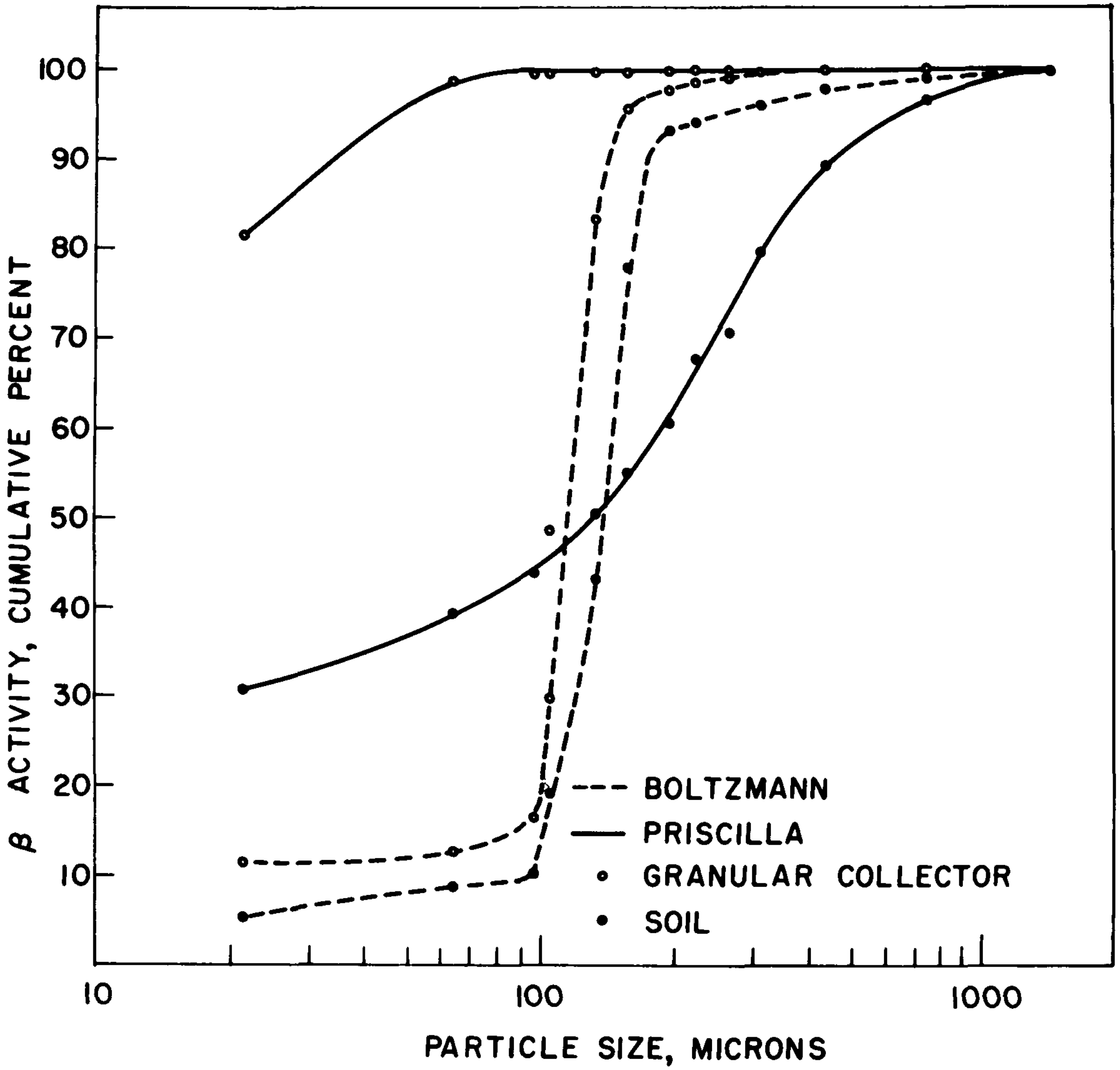


FIGURE 3.7 Comparison of Fallout Particle Size Distributions Determined by Soil and Granular Collector Samples Collected at Identical Locations.

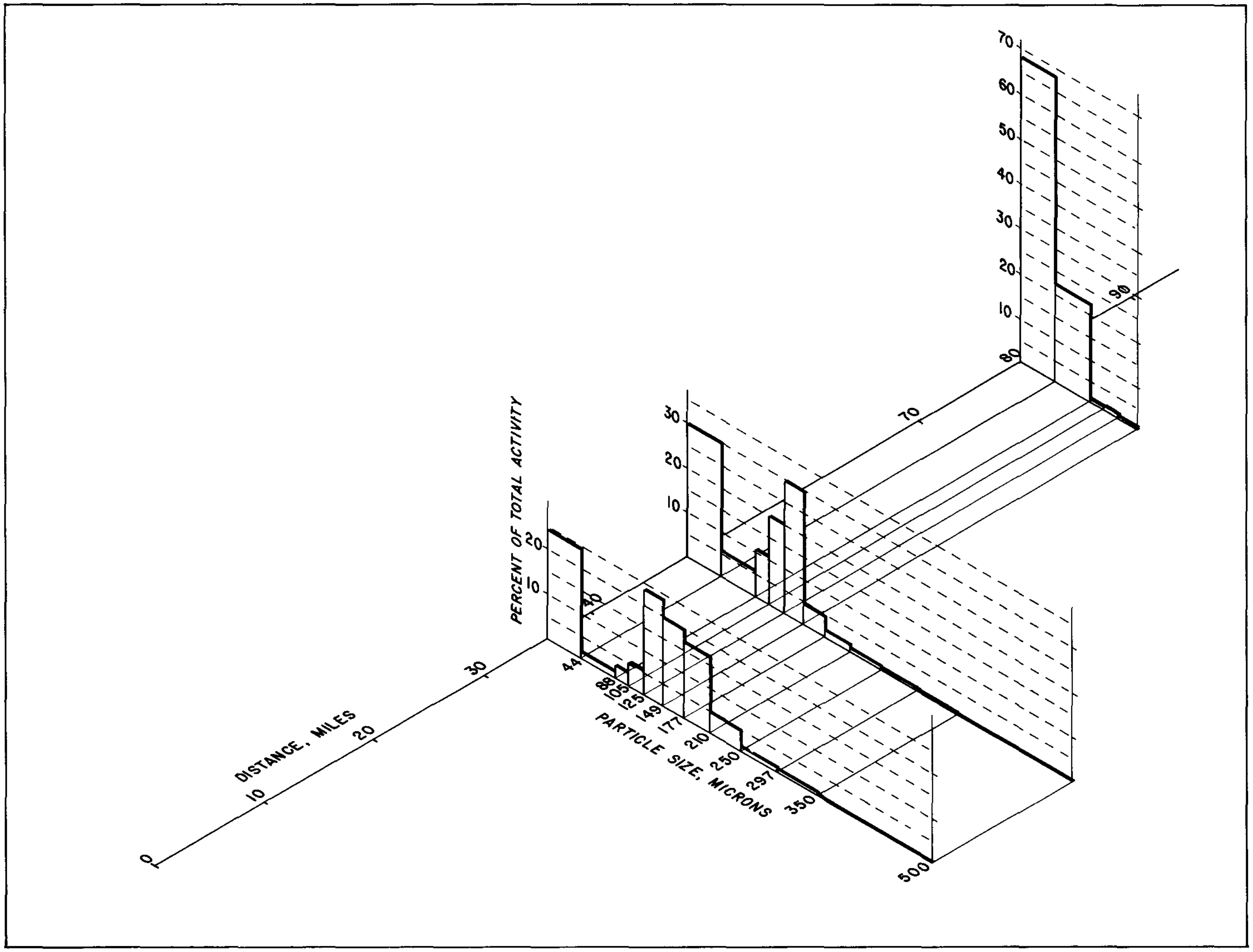


FIGURE 3.8 Total Particle Size Distribution of Fallout Material from Shot Boltzmann at Three Distances from Ground Zero.

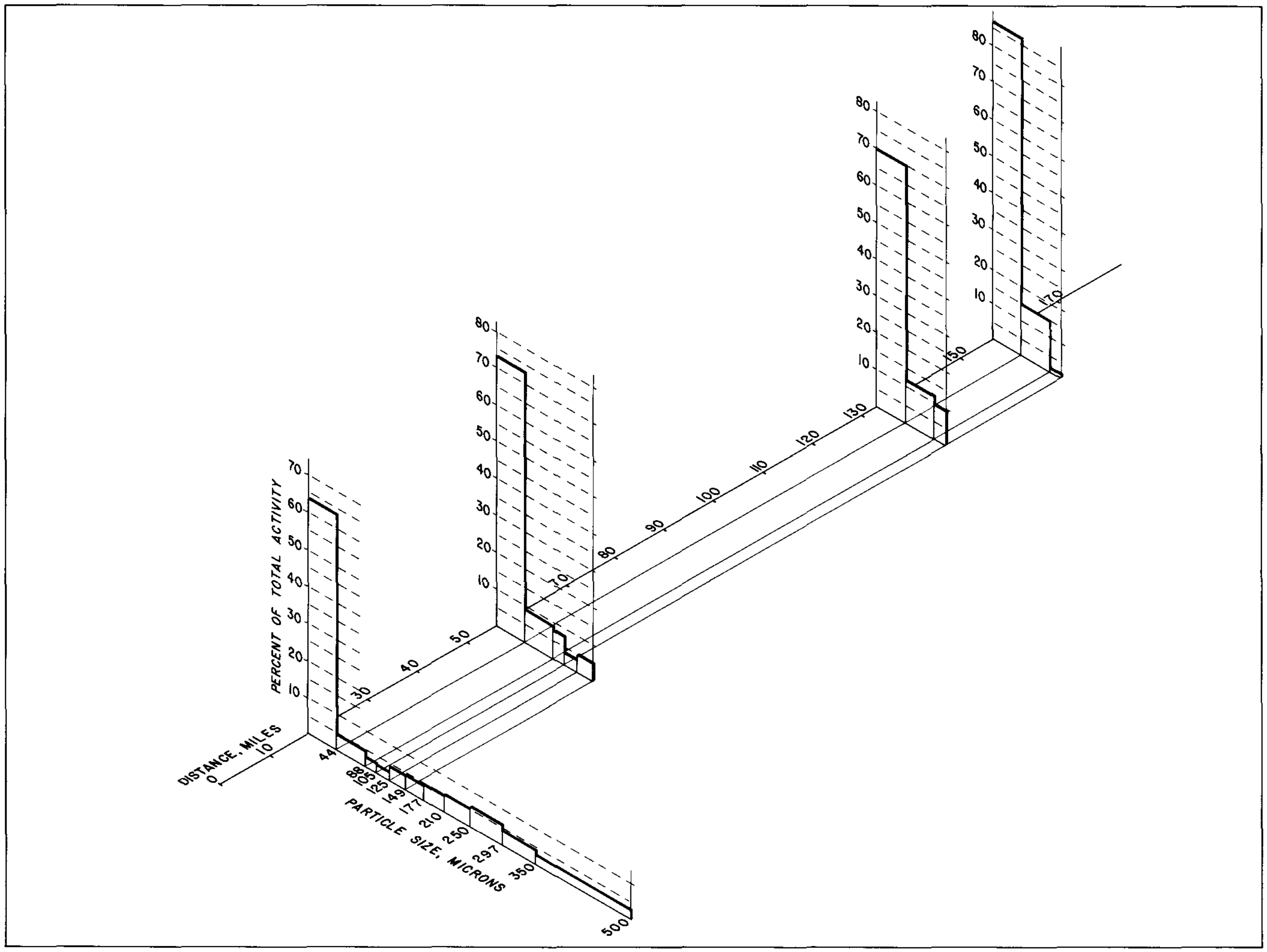


FIGURE 3.9 Total Particle Size Distribution of Fallout Material from Shot Priscilla at Four Distances from Ground Zero.

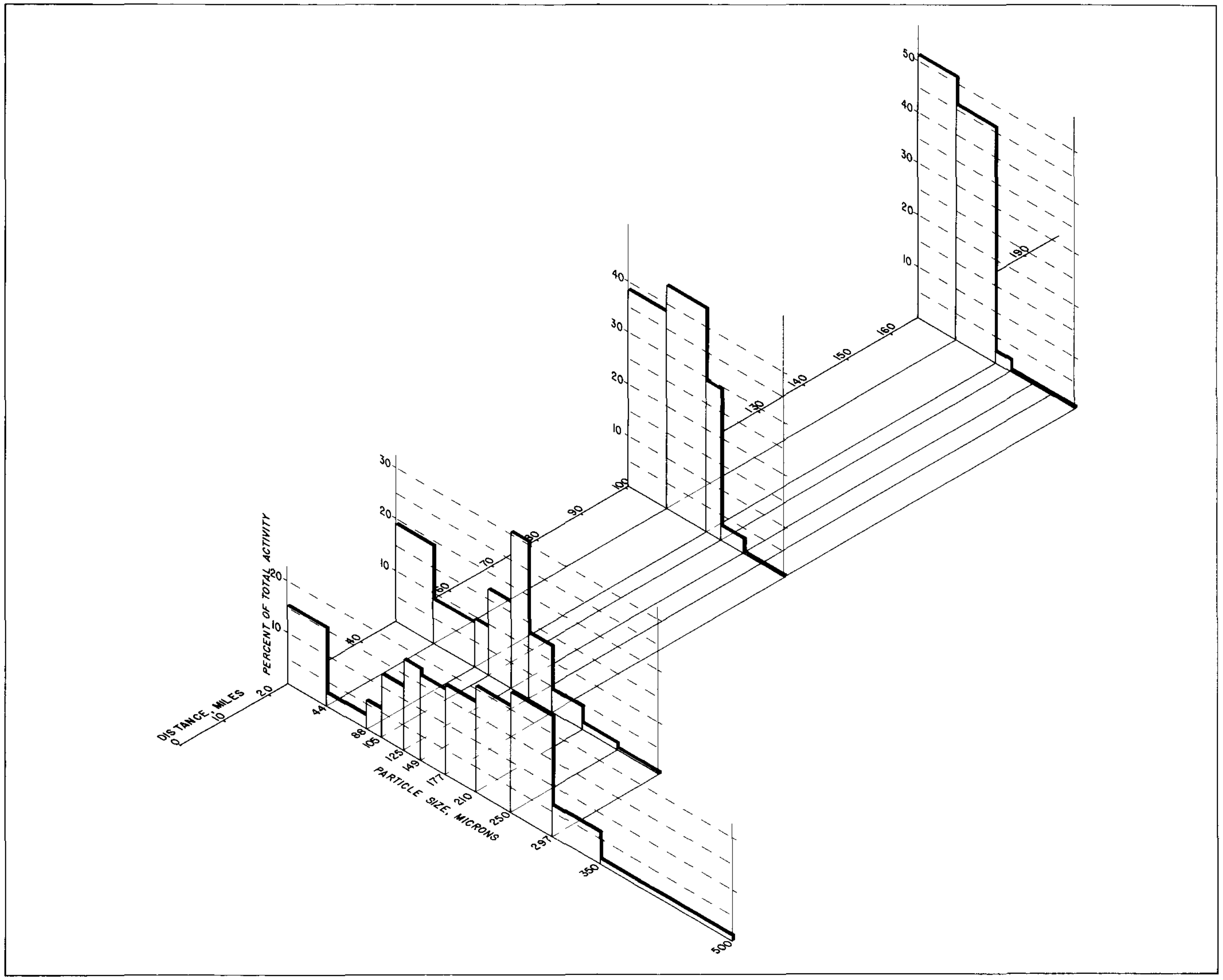


FIGURE 3.10 Total Particle Size Distribution of Fallout Material from Shot Smoky at Four Distances from Ground Zero.

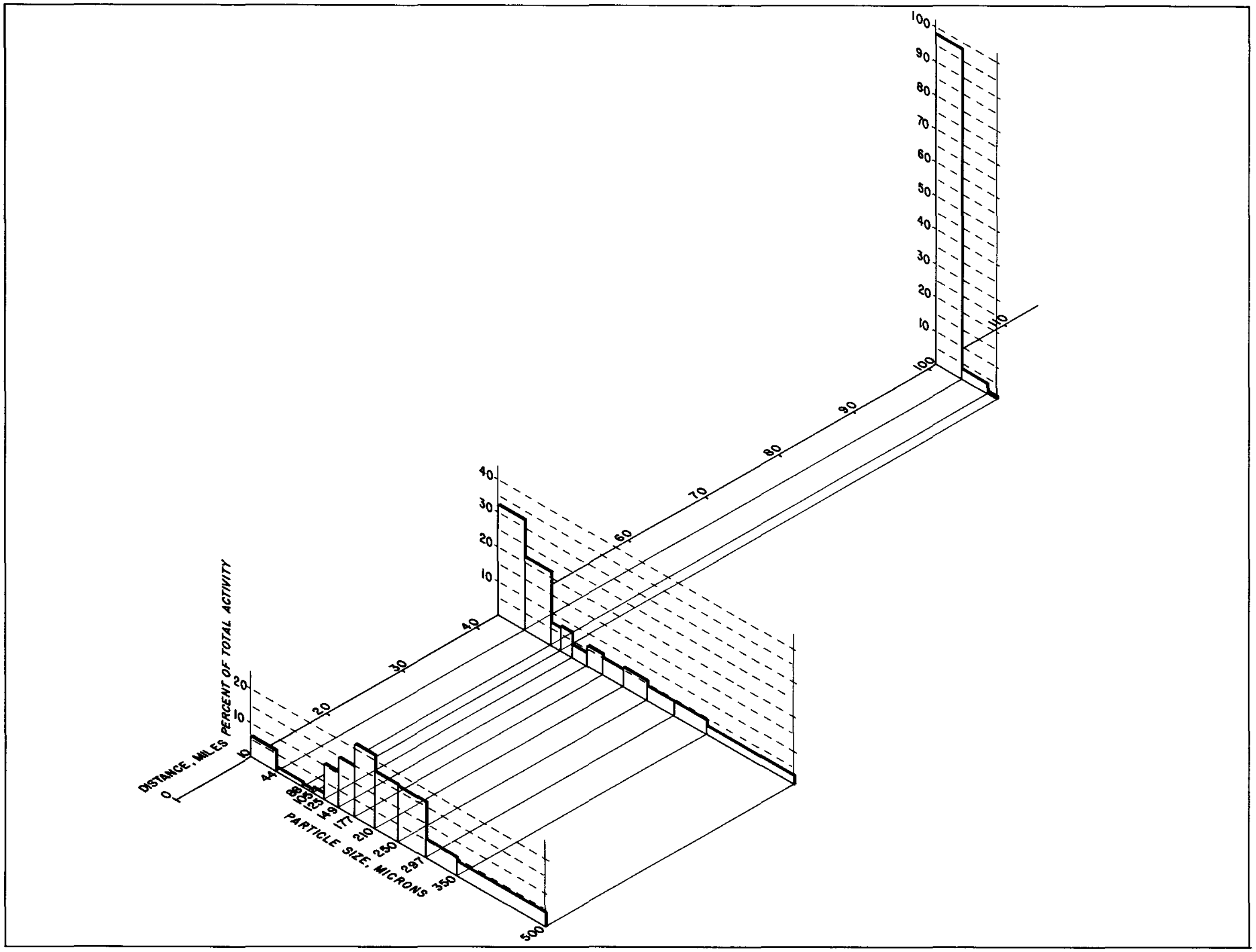


FIGURE 3.11 Total Particle Size Distribution of Fallout Material from Shot Whitney at Three Distances from Ground Zero.

graphically integrating the integrated arc radioactivity values of individual particle size ranges along the fallout midline as described in Chapter 2. The percentage contributions of the fallout fractions of various particle sizes, from Shots Boltzmann, Priscilla, and Smoky derived in this manner are tabulated in Table 3.1. The two tower shots had similar particle size distributions with approximately seventy percent of the fallout activity associated with particle sizes greater than 44 microns. The balloon Shot Priscilla had only approximately thirty percent of its fallout activity associated with such sizes.

TABLE 3.1 Particle Size Range Contribution to Fallout Deposited

Size Fraction, Microns	Pct of Total Beta Radioactivity, H + 12 hr		
	Boltzmann	Priscilla	Smoky
> 250	0.4	Nil	5.5
210 - 250	1.4	Nil	4.0
177 - 210	6.9	Nil	5.3
149 - 177	18.4	Nil	8.8
125 - 149	24.9	1.5	16.5
105 - 125	8.0	1.1	10.6
88 - 105	4.3	6.5	8.0
44 - 88	2.7	11.4	17.8
< 44	33.2	73.6	23.6

3.3.4 Particle Size Distributions Across Fallout Pattern Arcs

Examples of the distribution of individual particle size fractions across fallout pattern arcs appear in Figures 3.12 and 3.13 where particle size percentages across the closest Boltzmann (35 miles from ground zero) and Priscilla (18 miles from ground zero) arcs are presented. The total activity distributions across each arc are also presented for purposes of comparison.

The Boltzmann arc and, to a lesser extent, that of Priscilla demonstrate that the maximum percentage contributions of the various particle-size ranges occur at different locations in the traverse across the arc. Such distributions probably reflect the contributions of discrete elevation layers with the fallout cloud. The widespread distribution of less than 44 micron material suggests greater diffusion of smaller particle sizes within the cloud, relative to the larger size fractions.

Both Boltzmann and Priscilla arcs indicate that the location of maximum radiation intensity, at least in close-in areas, may be characterized by a variety of particle sizes probably originating from various strata within the cloud rather than a disproportionately large deposition of a given particle size range originating from a narrow cloud stratum. The lateral extremities of fallout pattern arcs in general were characterized by high percentages of less than 44 micron material; balloon shot arcs, in contrast to

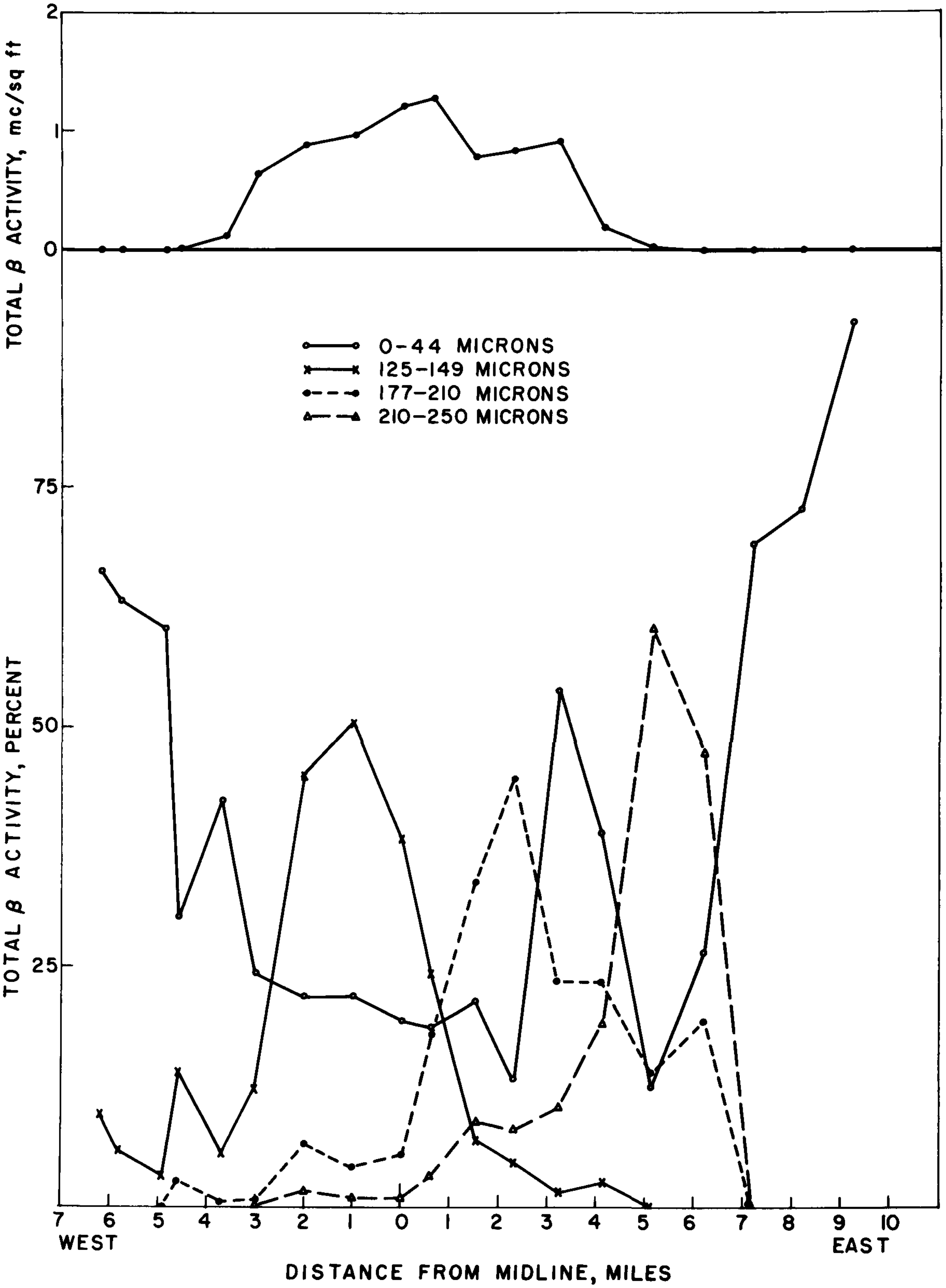


FIGURE 3.12 Percentage Contribution of Four Particle Size Fractions Across the Boltzmann 35-Mile Arc.

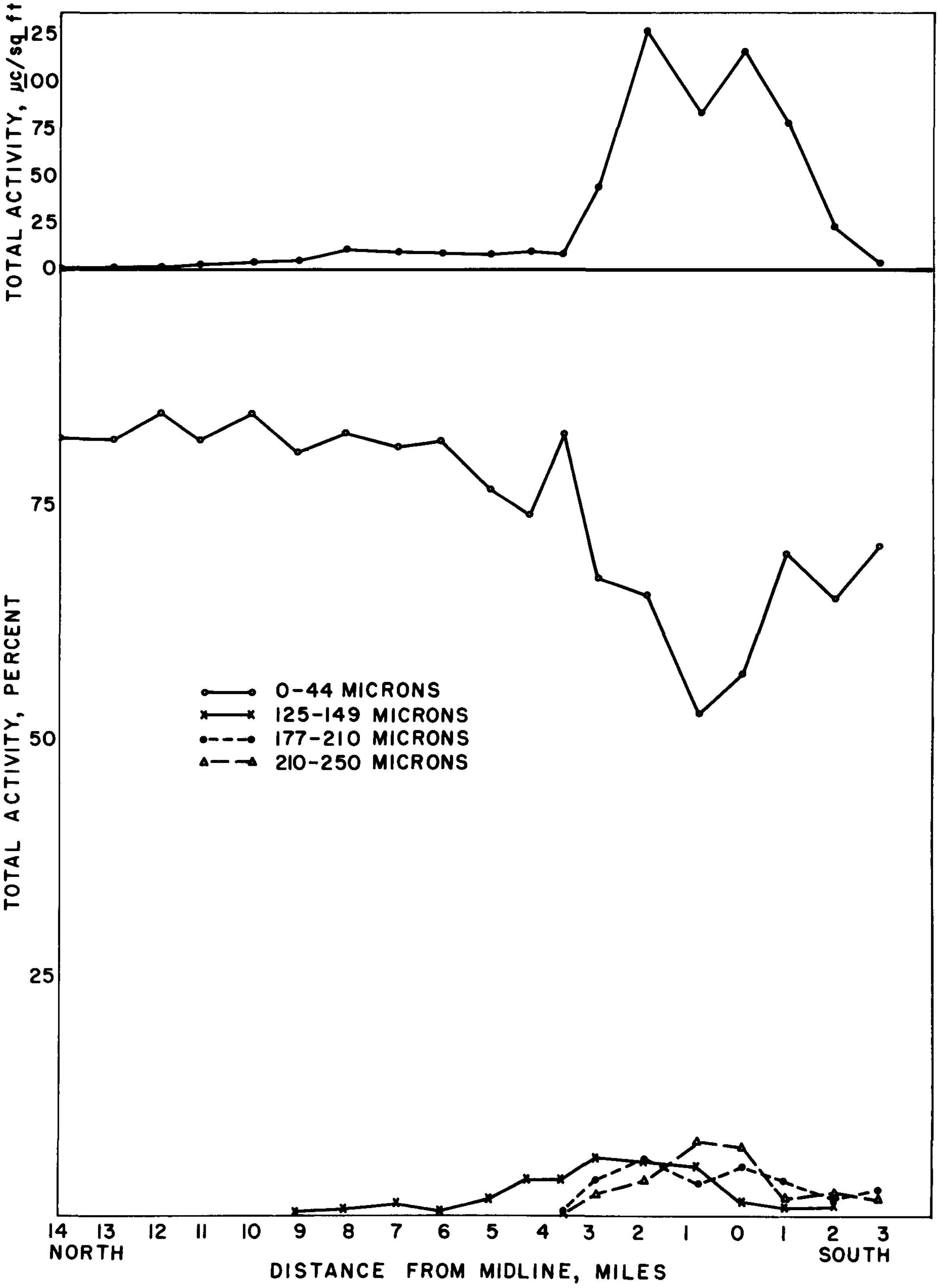


FIGURE 3.13 Percentage Contribution of Four Particle Size Fractions Across the Priscilla 18-Mile Arc.

close-in arcs of tower shots, demonstrated relatively high percentages of less than 44 micron material across the entire arc width, partially reflecting the early selective deposition of the fractions of larger size.

3.3.5 Comparison of Deposition of Total and the Less Then 44-Micron Fallout by Shots Priscilla and Smoky

The analysis of GC samples from tower and balloon shot patterns with respect to fallout radiation intensity and particle size distribution leads to two general observations: (1) The proportion of the fallout activity in less than 44 micron particles is greater for balloon shots than for tower shots, i. e., the larger sizes are less plentiful in balloon shots; and (2) the fallout radiation intensities produced by balloon shots are lower than those of tower shots at similar locations.

Further quantification of the differences between tower and balloon shot fallout with respect to level and particle size requires minimization of variables other than type of support, e. g., yield and detonation height. This requirement is approached by the Shots Priscilla and Smoky which had similar yields (37 and 44 kt, respectively) and the same height of detonation (700 feet) Consequently, the effects of the heavy cab and 700 foot steel tower could be compared to those of the light cab and balloon support on fallout level and particle size at different fallout times if one assumed the interception of the fireball was nearly the same for both shots.

The total beta radioactivity value and that of the less than 44-micron particle size fraction for close-in deposition were determined by integration of measured μc/sq ft values across the two patterns at various distances from ground zero. The integrated values of (curies/sq ft)(miles) or c/ft at H + 12 hours are plotted as a function of relative fallout time-of-arrival in Figure 3. 14. The total beta and less than 44 micron fraction activities derived from Figure 3. 14 for various fallout times are listed in Table 3. 2.

While the total fallout activities from both shots decreased as a function of fallout time, the total beta activity values from Shot Smoky decreased at a more rapid rate due to the higher percentage contributions of larger particle sizes. The total fallout activity levels produced by Shot Smoky ranged from 49 to 22 times those produced by Shot Priscilla over the H + 1 to H + 15 hour time period. Radioactivity levels of less than 44 microns size fraction from both shots, likewise, decreased with fallout time-of-arrival. However, in Shot Smoky, the less than 44 micron levels decreased at a slightly less rapid rate than those from Shot Priscilla; and the less than 44 micron levels of Shot Smoky ranged from 8 to 14 times those of the Shot Priscilla over the H + 1 to H + 15 hour time period.

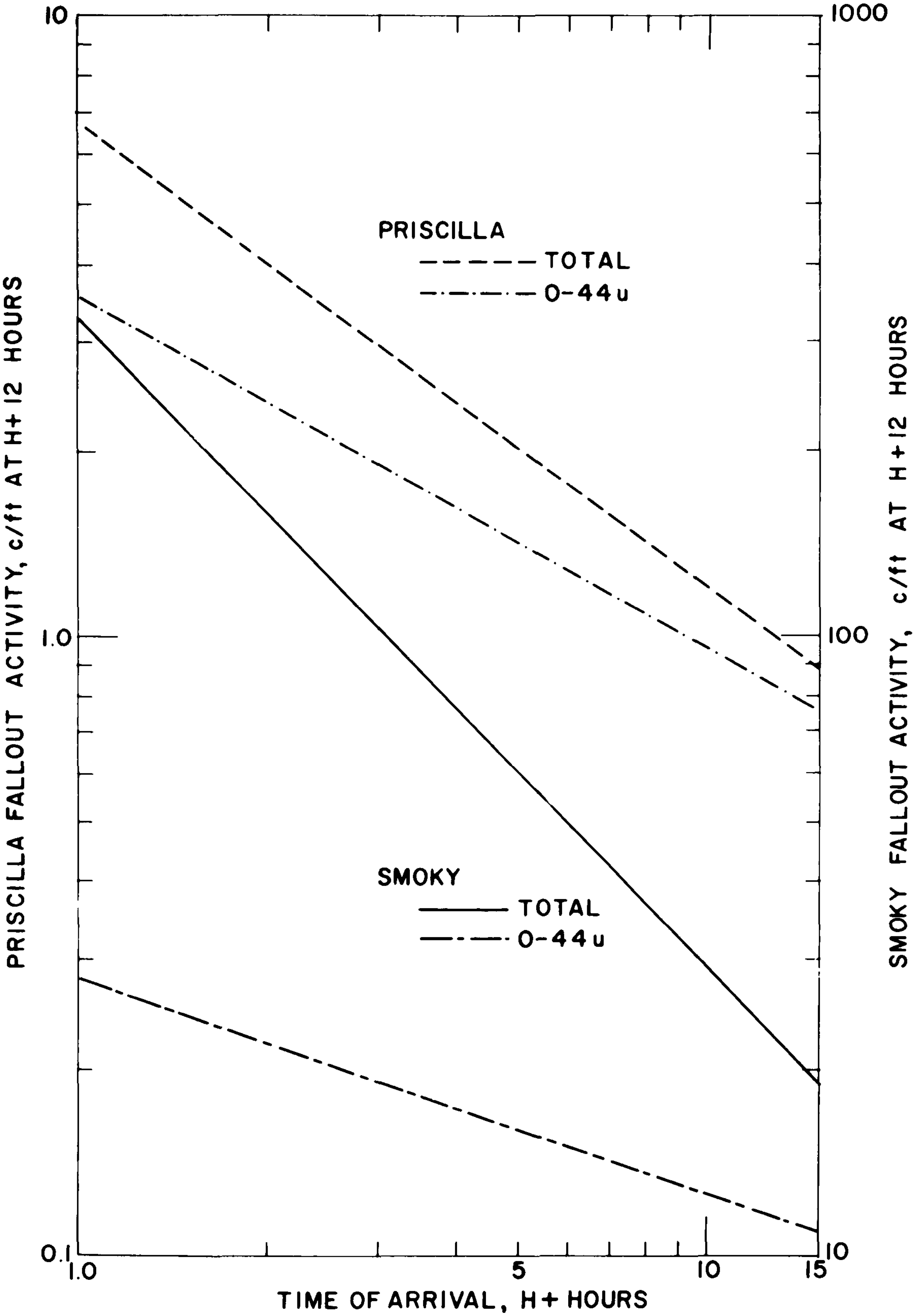


FIGURE 3.14 Integrated Total and <44 Micron Beta Activity, Deposited by Shots Priscilla and Smoky Versus Fallout Time-of-Arrival.

TABLE 3.2 Comparison of Total and < 44 Micron Integrated Activity from Shots Smoky and Priscilla

Relative Fallout Time	Total Integrated Activity			< 44 μ Integrated Beta Activity			< 44 μ, Pct of Total Beta Activity	
	c/ft, H + 12 Hours		Ratio	c/ft, H + 12 Hours		Ratio		
H + hr	Smoky	Priscilla	Smoky/Priscilla	Smoky	Priscilla	Smoky/Priscilla	Smoky	Priscilla
1	330	6.72	49.1	27.9	3.54	7.88	8.45	52.7
2	158	4.00	39.5	21.8	2.38	9.16	14.0	59.5
3	103	2.94	35.0	19.1	1.88	10.2	18.5	63.9
4	76.0	2.37	32.1	17.2	1.60	10.8	22.6	67.5
5	60.0	2.00	30.0	15.9	1.42	11.2	26.5	71.0
6	50.0	1.75	28.6	15.0	1.27	11.8	30.0	72.6
7	42.2	1.56	27.1	14.2	1.17	12.1	33.6	75.0
8	36.5	1.41	25.9	13.6	1.08	12.6	37.3	76.6
9	32.5	1.28	25.4	13.0	1.01	12.9	40.0	78.9
10	29.0	1.19	24.4	12.6	0.95	13.3	43.3	79.8
11	26.3	1.12	23.5	12.2	0.90	13.6	46.3	80.4
12	23.9	1.04	23.0	11.8	0.85	13.9	49.4	81.7
13	22.2	0.98	22.7	11.5	0.82	14.1	51.8	83.2
14	20.6	0.93	22.2	11.2	0.79	14.3	54.4	84.4
15	19.0	0.88	21.6	10.9	0.75	14.5	57.4	85.2

The percentage contribution of radioactivity of the less than 44 micron size fraction of the radioactivity of the total sample increased with fallout time-of-arrival for both shots. The percentage of Priscilla of less than 44 micron size fraction was considerably higher than that of Shot Smoky over the entire 1 to 15 hour fallout time range.

If the data of Figure 3.14 are plotted as a function of distance from ground zero rather than time-of-arrival, a graphical integration of each curve yields the number of curies of contamination. By this method Shot Smoky deposited 76 and Priscilla 1.46 megacuries (H + 12 hours) of beta activity from H + 1 to H + 12 hours fallout times. Similar values of radioactivity in the less than 44 micron fraction from Shots Smoky and Priscilla are 14.8 and 1.04 megacuries, respectively. Therefore, Smoky deposited 52 times more total beta radioactivity and 14 times more radioactivity in the less than 44 micron fraction than Priscilla in the H + 1 to H + 12 hour fallout period.

3.4 SUMMARY AND CONCLUSIONS

1. Maximum percentage contributions of different particle sizes occurred at different locations on fallout pattern arcs. Some locations of maximum dose rates across a pattern resulted from moderate percentages of a variety of particle sizes rather than a high percentage of a single size range. Lateral extremities of arcs were characterized by high percentages of less than 44 micron material.
2. Fallout material less than 44 microns in diameter occurred at close-in arcs as well as at distant arcs while the 44 to 88 micron fraction of fallout material was minimal at close-in distances. The majority of fallout activity from the balloon mounted Shot Priscilla consisted of particles less than 44 microns in diameter as close to ground zero as 18 miles; larger particles predominated at such distances in fallout material from tower mounted shots.
3. Within the limits of one mile from ground zero and to distances at which fallout occurred at H + 12 hours approximately 70 percent of the fallout activity was associated with particle sizes greater than 44 micron diameter from tower mounted shots while the balloon-mounted Shot Priscilla had only 30 percent of the activity associated with this size range, larger than 44 microns.
4. Within the limits of H + 1 to H + 12 hour fallout time, Shot Smoky deposited 52 times more total beta radioactivity and 14 times more or less than 44 micron fraction beta radioactivity than the Priscilla balloon shot, both of which had similar yields and identical detonation height.
5. Variation between duplicate 4.73 sq ft GC samples compared favorably with variation among 12 gummed paper or resin plate samples; variations among collector replicates generally decreased as fallout activity increased.
6. Gummed paper samples, on the average, yielded slightly higher activity per unit area than GC samples at the same location while resin-coated plates yielded values considerably lower than the GC.

7. Soil samples demonstrated entrapment of small particles by soil material of larger particle size. However, the reliability of unit area activity values derived from surface soil was affected by time of radioassay due to residual contamination from previous test series and the resultant differential decay rates.

REFERENCES

1. W. J. Dixon and F. J. Massey, Jr.; "Introduction to Statistical Analysis"; 2nd ed. 1957; McGraw-Hill Book Co., Inc., New York, N. Y.; Unclassified.

2. L. Baurmash and others; "Distribution and Characterization of Fallout and Airborne Activity from 10 to 160 miles from Ground Zero, Spring 1955"; Project 37.2 (CETG), Operation Teapot, WT-1178, November 1958; Atomic Energy Project, School of Medicine, University of California, Los Angeles, California; Unclassified.

CHAPTER 4

RADIATION DECAY PROPERTIES AND ENERGY SPECTRA OF FALLOUT DEBRIS

4.1 INTRODUCTION

Beta decay and gamma decay constants, the K-value used in the expression $A=A_0T^{-k}$, were determined on fallout debris from various detonations. The measurements were made by gamma radiation recorders located in the fallout patterns and in the laboratory on samples of fallout material selected according to particle size range, fallout time-of-arrival, and type of device support.

4.2 PROCEDURE

Field radiation measurements were made by portable radiation continuous recorders (PRAM) set up on various arcs along the predicted path of fallout. See Appendix A for details.

Samples for decay and energy spectra studies in the laboratory consisted of two-inch diameter discs cut from gummed paper exposed directly to fallout and from gummed paper on which particle size fractions obtained from GC's were uniformly spread. These discs were mounted in plastic Petri dishes and measurements made as described in Appendix A.

Gamma energy spectra were obtained by measurements of GC samples on a recording gamma ray spectrometer as described in Appendix A. Calibration was accomplished using Na^{22}, W^{185}, Cs^{137}, and Co^{60} standards.

4.3 RESULTS AND DISCUSSION

4.3.1 Beta and Gamma Radiation Decay

4.3.1.1 Gamma Radiation Decay Measurements in Fallout Patterns

Measurements of gamma dose rate by portable radiation continuous recorders were obtained at various locations where fallout deposition was apparently complete by H + 2 to H + 6 hours in the fallout patterns from Shots Boltzmann, Priscilla, Hood, Diablo, Shasta, and Smoky. Data from the various locations were normalized to yield curves descriptive of the individual shots as presented in Figure 4.1.

The decay slopes of the curves from the several shots are variable over short common time intervals. However, the effective decay rates between H + 3 and H + 12 hours, i.e., the slopes of lines drawn between H + 3 and H + 12 hour values, are more similar, with the k-value ranging from -0.96 to -1.27 with a mean value of -1.10 ± 0.12.

Laboratory measurements of photon emission rates were not initiated sufficiently early for comparison with field dose-rate measurements with the exception of Shot Shasta after H + 10 hours and Smoky after H + 8 hours. The composite laboratory gamma decay curves are superimposed on field dose-rate curves over the appropriate time intervals in Figure 4.1. The two Shasta curves diverge over the H + 10 to H + 16 hours common time period while the two Smoky curves demonstrate good agreement over the H + 8 to H + 27 hours common time period. While the data are too sparse for firm conclusions, the Smoky curves suggest that dose-rate decline as measured by the ion-chanber of the PRAM may be approximated by laboratory measurements of photon emission decline at least over certain early time periods.

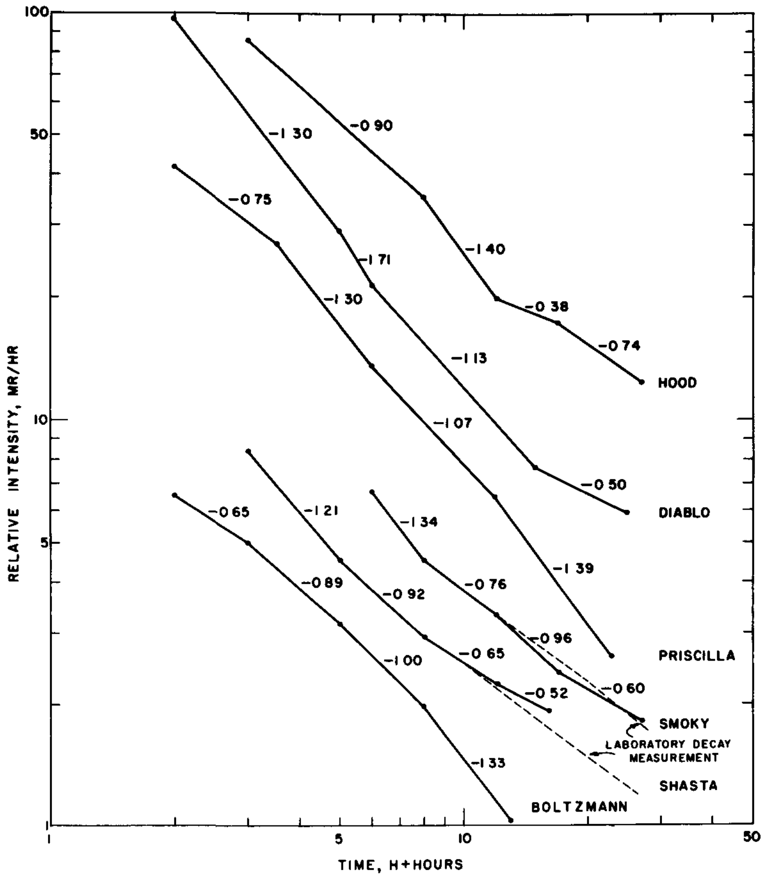


FIGURE 4.1 Mean Gamma Dose-rate Decay of Fallout Produced by Tower and Balloon Mounted Shots Measured in the Patterns by Portable Radiation Recorders.

4 3.1 2 Decay of Different Particle Size Fractions

The results of beta and gamma decay measurements of samples of different particle size ranges collected at the same or nearly the same fallout time are presented in Figures 4.2 (Boltzmann), 4.3 (Priscilla), 4.4 (Smoky), and 4.5 (Whitney).

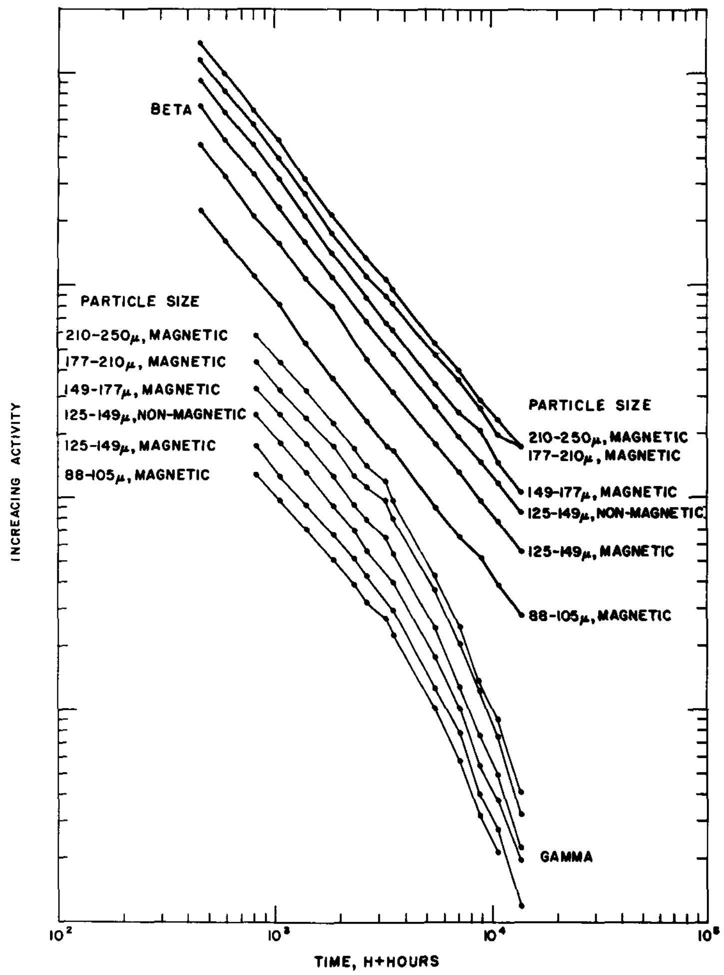


FIGURE 4.2 Beta and Gamma Decay Curves of Boltzmann Fallout of Different Particle Size and Magnetic Properties. (Samples from Stations Having Fallout Time-of-Arrival from 1.4 to 2.7 hours).

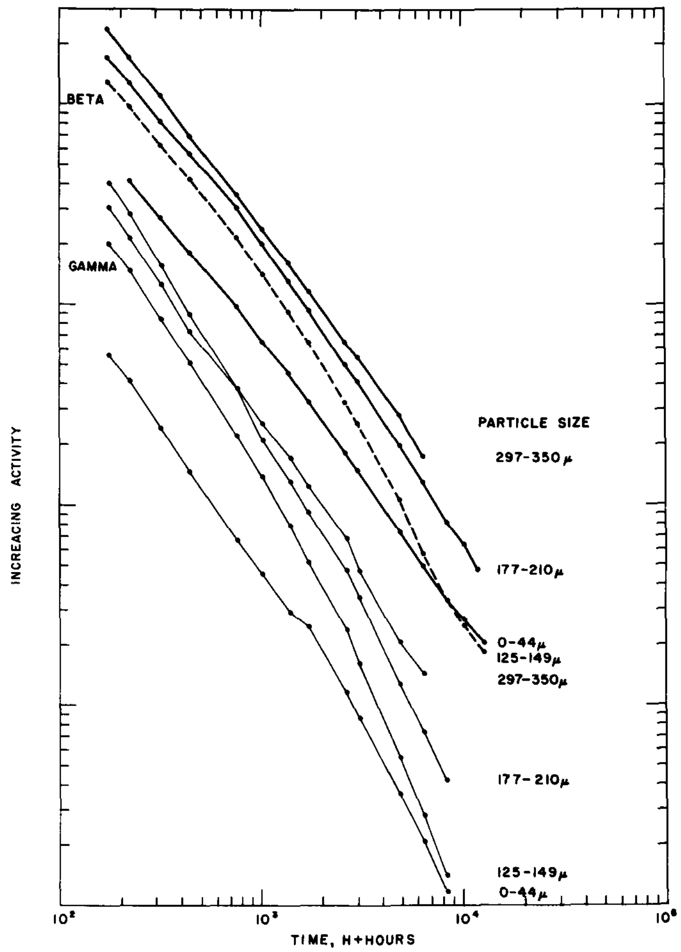


FIGURE 4.3 Beta and Gamma Decay Curves of Priscilla Fallout Material of Four Particle Size Fractions. (Samples from a Station Having Fallout Time-of-Arrival of 2.4 Hours).

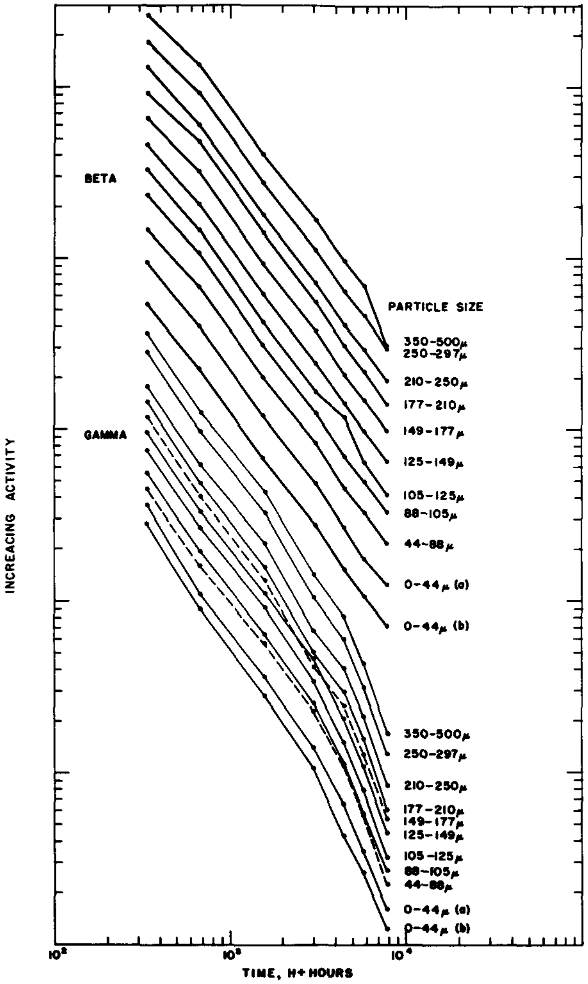


FIGURE 4.4 Beta and Gamma Decay Curves of Smoky Fallout of Eight Particle Size Fractions. (Samples from Station Having Fallout Time-of-Arrival from 0.4 to 1.3 Hours).

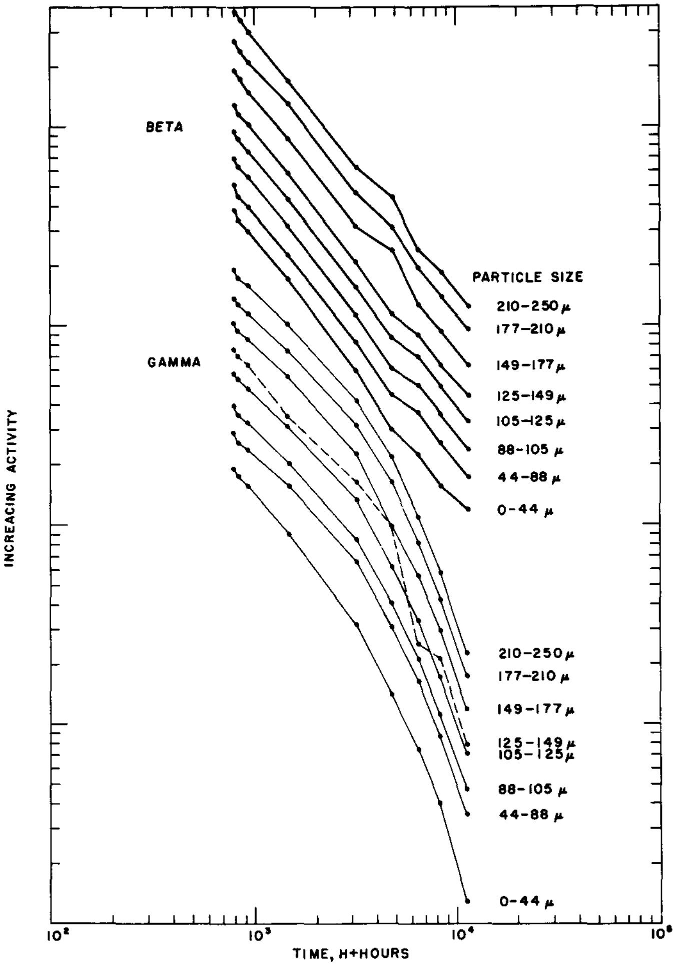


FIGURE 4.5 Beta and Gamma Decay Curves of Whitney Fallout of Different Particle Size Fractions. (Samples from Station Having Fallout Time-of-Arrival of 3 Hours).

The beta decay curves of fallout debris of different particle sizes from individual shots are very similar for the most part, including those fractions which were separated by magnet and are labelled magnetic and nonmagnetic fractions (Boltzmann), see Chapter 5 for details. Slight differences in slope over common time periods are apparent in the Whitney decay curves, which demonstrate a tendency for more rapid decay with decreasing particle size over the intervals of H + 444 to H + 800 hours and H + 4100 to H + 6000 hours. A trend of this type could reflect the effects of gross energy fluctuations upon different particle self-absorption rates, however, similar trends are observed in corresponding gamma decay slopes where absorption should be negligible.

The observed differences in beta slopes over common time periods are of the order to be anticipated from the radionuclides determined by radiochemical analysis of different particle size fractions. In Figure 4.6, the observed beta decay curves of Priscilla fallout samples (Figure 4.3) are compared to values derived from the D + 30 day radiochemical analysis of duplicate samples (See Appendix D)

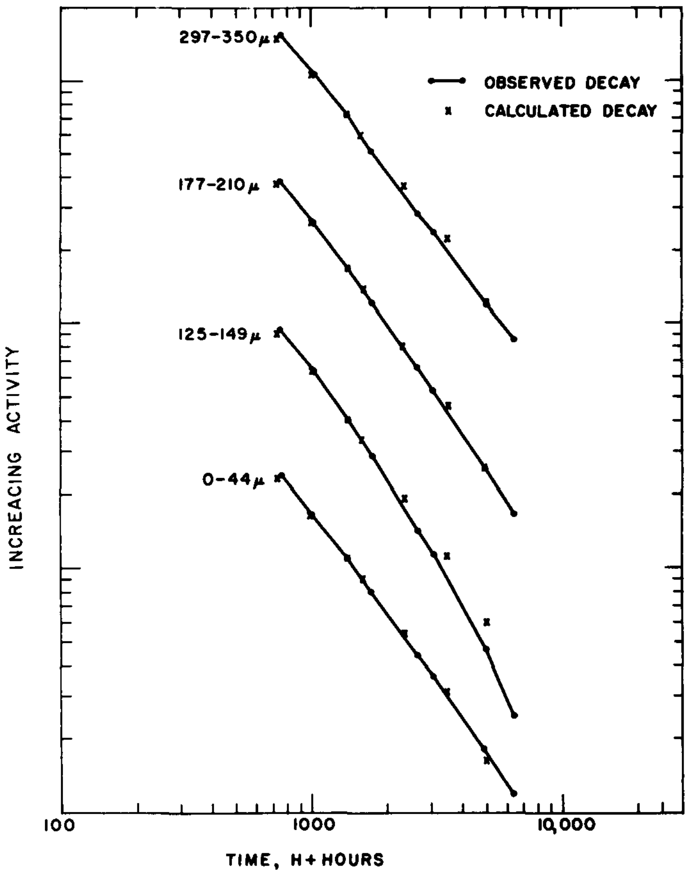


FIGURE 4.6 Observed and Calculated Beta Decay of Priscilla Fallout of Four Particle Size Fractions.

Calculations were based on the inclusion of daughter products, an estimation of the quantity of Pr^{143} on the basis of equivalency to Ce^{141} at D + 30 days (Reference 1), and no detection of the 0.04 Mev beta of Ru^{106}. Radionuclides of barium, cerium, praseodymium, ruthenium, strontium, yttrium, zirconium, and daughter products accounted for approximately 95 percent of the activity observed at D + 30 days, and the calculated decay curves approximate the observed curves with the exception of the 125-149 micron size fraction. The general similarity of the beta decay curves of different size fractions and the lack of radiochemical concurrence suggest that the 125-149 micron decay sample was not representative of that size fraction Further, the agreement between observed and calculated decay indicates that differences in content of individual radioisotopes of the order of a factor of two among different particle size fractions will not produce detectable differences in decay curves where a large number of contributing isotopes are involved

The observed gamma decay slopes of different particle size fractions from individual shots generally tend to be more variable than corresponding beta decay slopes but distinct families of curves were observed for each shot.

4 3 1.3 Decay of Particles with Different Arrival Times

Fallout material of the same size fraction collected at different fallout times within the pattern of a specific shot produced very similar decay curves Beta and gamma decay curves of < 44 micron fallout fractions collected at five fallout times in the Priscilla pattern and at eight fallout times in the Hood pattern are presented in Figures 4.7 and 4 8, respectively. These gamma decay slopes generally are more similar than those for particles of different size.

4.3.1 4. Composite Decay Curves of Individual Shots

The general similarity of decay curves of different particle sizes and of different times of fallout permits the construction of beta and gamma decay curves which are based upon the normalized data of the various measurements obtained and upon characteristics of individual shots Where decay measurements were not obtained over specific time intervals, decay curves were continued on the basis of the normalized slopes observed for the other shots The composite beta and gamma decay curves, with slope designations applying to different time intervals, appear in Figures 4.9 and 4.10 respectively

The beta decay curves of Figure 4.9 represent six tower mounted shots (Diablo, Fizeau, Whitney, Smoky, Shasta, and Boltzmann) and two balloon mounted shots (Hood and Priscilla). With the exception of the Hood curve that has slopes of < -1 over the time interval of H + 100 to H + 700 nours, the curves are generally similar and approximate the -1 2 slope to the time of H + 1000 hours After H + 1000 hours, the decay tends to be more rapid than would be indicated by $T^{-1.2}$ The dissimilarity of the Hood curve is presently unexplained Radionuclide analyses were not performed.

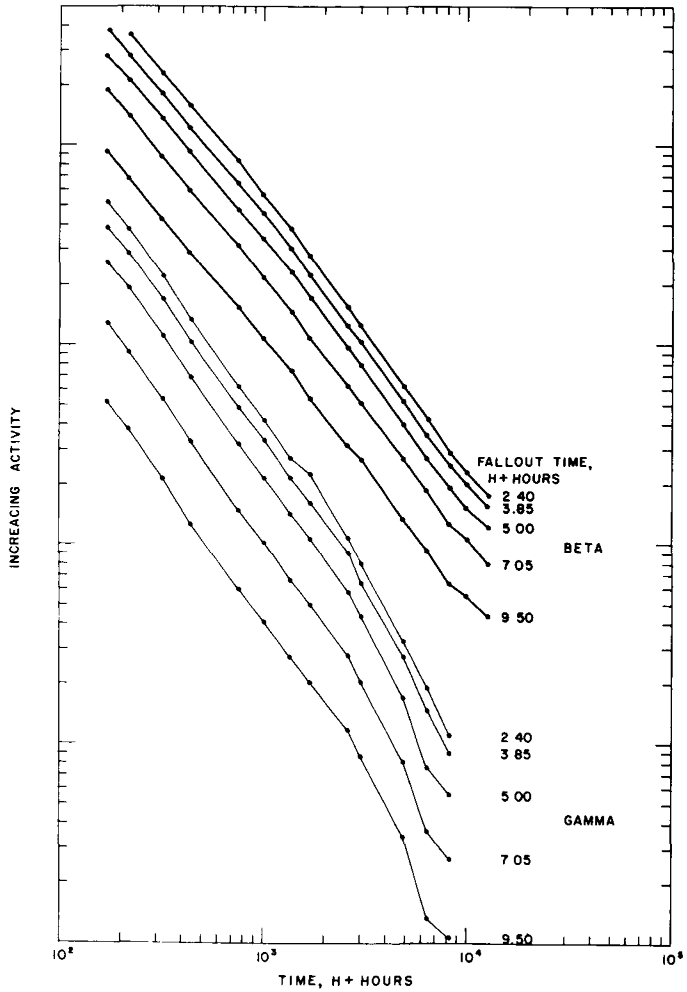


FIGURE 4.7 Comparison of Beta and Gamma Decay curves of < 44 Micron Size Fraction of Priscilla Fallout from Stations at Five Different Times-of-Arrival.

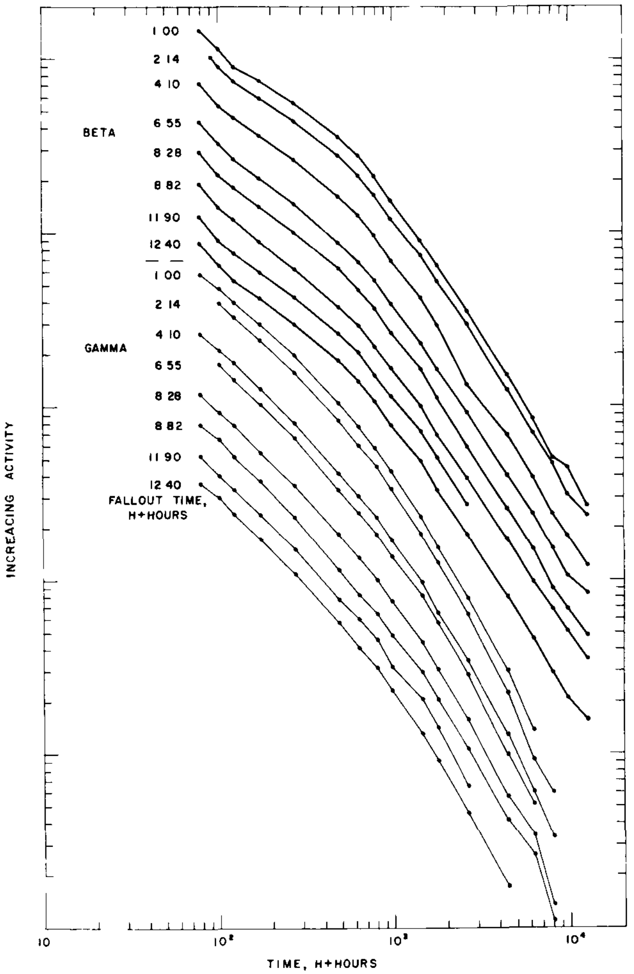


FIGURE 4.8 Beta and Gamma Decay Curves of < 44 Micron Size Fractions of Hood Fallout from Stations at Eight Different Times-of-Arrival.

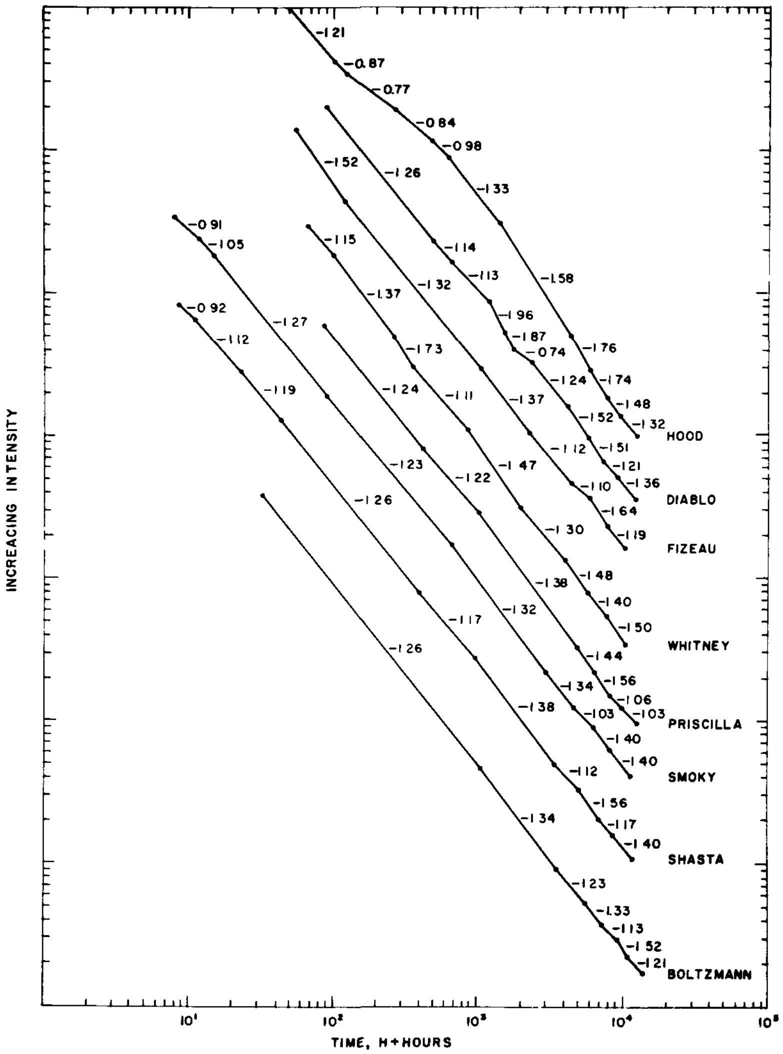


FIGURE 4.9 Beta Decay Curves of Fallout from Eight Shots.

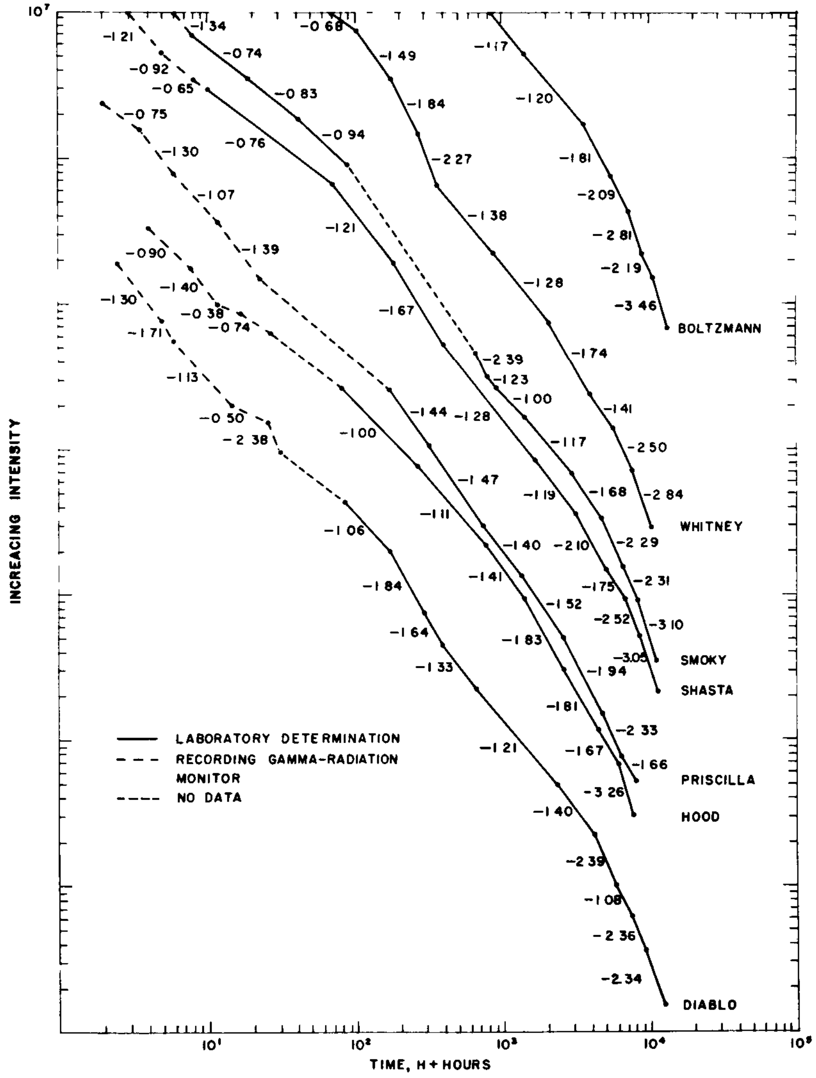


FIGURE 4.10 Gamma Decay Curves of Fallout from Seven Shots.

The gamma decay curves of Figure 4.10 represent five tower mounted shots (Boltzmann, Whitney, Smoky, Shasta, and Diablo) and two balloon mounted shots (Priscilla and Hood). In addition to laboratory measurements, mean values derived from the PRAM'S were included to permit extension of the decay curves from fallout time to time of station recovery.

The gamma decay curves for individual shots are generally more dissimilar than corresponding beta decay curves with the exception of the Smoky and Shasta curves. All curves are characterized by slopes of more rapid decay than -1.2 over the time interval from H + 200 to H + 700 hours, with the exception of the Hood curve where slopes of approximately -1.0 are observed. Beyond H + 1000 hours, the rate of decay tends to increase, to slopes of the order of -3.0.

4.3.1.5 Composite Plumbbob Series Decay Curves

Based on the beta curves presented in Figure 4.9 (with the exception of Hood) and the gamma curves in Figure 4.10, composite beta and gamma decay curves descriptive of the Plumbbob series are presented in Figure 4.11. A theoretical curve that was derived by Hunter and Ballou and based on the slow neutron fission of U^{235} is included to illustrate the nature of slope variations to be expected for experimental data in contrast to the generalized decay slopes of -1.2.

The beta decay curve is characterized by negative slopes of less than 1.2 from H + 9 to H + 18 hours, slopes approximating -1.2 from H + 18 hours to H + 1000 hours, and slopes greater than -1.2 from H + 1000 to H +10,000 hours. The gamma decay curve is characterized by an initial slope of -2.18 from H + 1 to H + 2 hours followed by slopes varying from -1.0 to -0.78 from H + 6 to H + 100 hours and slopes of -1.2 to 1.68 from H + 100 to H + 3000 hours. Beyond 3000 hours the decays become increasingly more rapid with a slope of -3.12 at about H + 10,000 hours. The beta composite curve has a maximum variation of approximately ±10 percent due to veriations in the individual curves while the gamma has a maximum variation of about ± 35 percent.

The Plumbbob composite beta and gamma decay curves were utilized for the extrapolation of experimental data presented elsewhere in this report (with the exception of Shot Hood) to common times after shot. Hood radioactivity values were extrapolated on the basis of the Hood beta and gamma decay curves appearing in Figures 4.9 and 4.10.

4.3.2 Beta-to-Gamma Radioactivity Ratios

Beta-to-gamma ratios were more sensitive indicators of radioisotopic variations among fallout samples of different particle sizes or shot derivation than were the decay curves. Figures 4.12, 4.13, and 4.14 present beta-to-gamma ratios of different size fractions of fallout material produced by Shots Boltzmann, Priscilla, and Whitney,

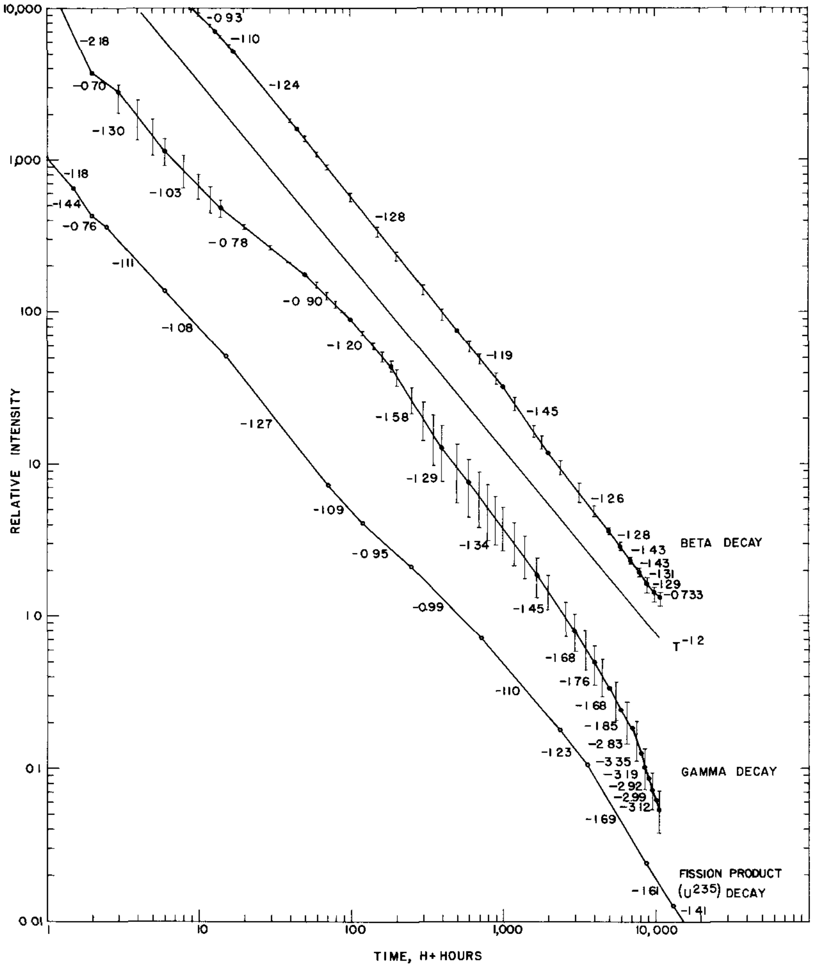


FIGURE 4.11 Plumbbob Composite Beta and Gamma Decay Curves.

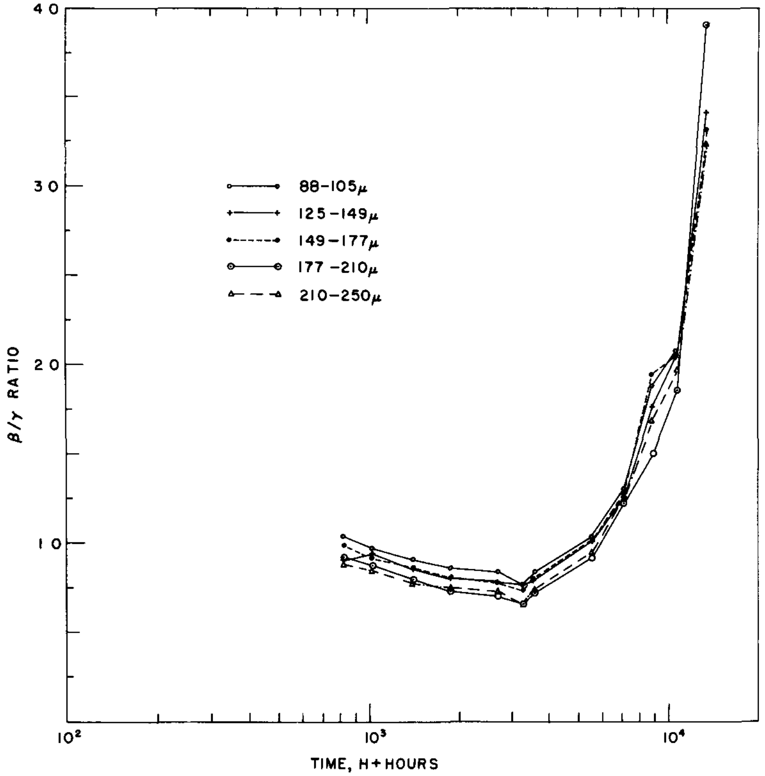


FIGURE 4.12 Comparison of Beta-to-Gamma Ratio Versus Time of Five Particle Size Fractions from Boltzmann Fallout.

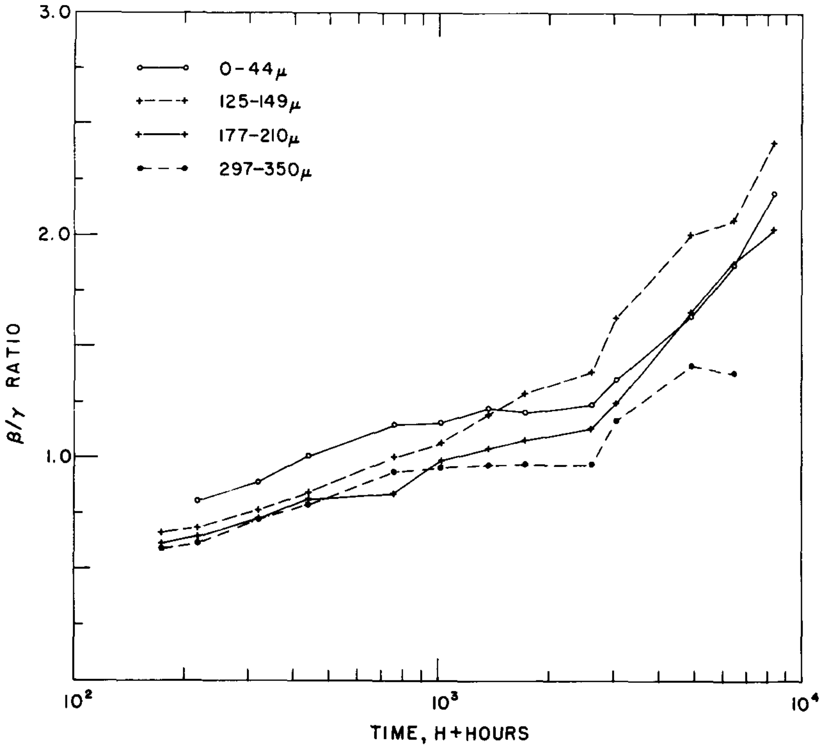


FIGURE 4.13 Comparison of Beta-to-Gamma Ratio Versus Time of Four Particle Size Fractions from Priscilla Fallout.

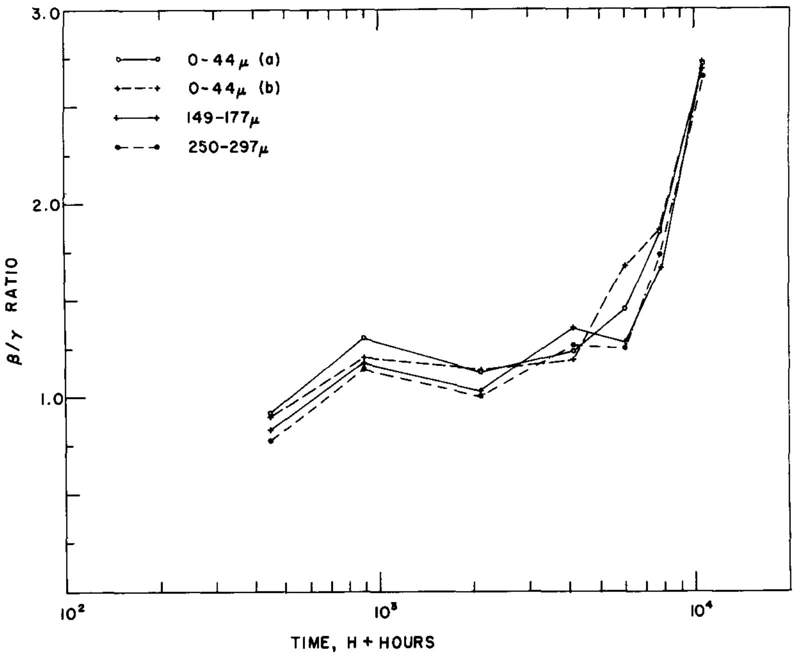


FIGURE 4.14 Comparison of Beta-to-Gamma Ratio Versus Time of Four Particle Size Fractions from Whitney Fallout.

respectively, to a maximum time of H + 12,000 hours. Three general observations may be made: (1) the curves derived from different particle sizes of the individual shots generally are similar in shape, (2) there is a tendency for the highest ratios to be associated with the smaller particle size fractions over the entire analysis period, and (3) the slopes of the curves are distinctive for each shot.

Figure 4.15 presents beta-to-gamma ratio curves descriptive of the tower mounted Shots Boltzmann, Diablo, Shasta, Smoky and Whitney and the balloon mounted Shots Priscilla and Hood. The curves represent mean beta-to-gamma ratios of all samples analyzed from each shot. Although the tower shot ratios varied considerably among themselves, as a group they were consistently lower than corresponding balloon shot ratios after H + 1500 hours. It should be noted, however, that the majority of balloon shot fallout samples was of the less than 44 micron size fraction which tended to have higher ratios regardless of origin, as described above. In general, the beta-to-gamma ratios were less than one from H + 70 to H + 350 hours, approximately one from H + 350 to H + 3000 hours, and increased to approximately three from H + 3000 to H + 12,000 hours.

4.3.3 Gamma Energy Spectra

Since a single channel analyzer with a continually decreasing baseline was used to determine the gamma spectrum of the selected samples, there was a loss in resolution between the energy peaks of the large number of radioisotopes to be found in fallout material Therefore, it was possible only to separate the gamma spectrum into ranges of energy.

From five to eight samples of different particle size and/or fallout time from each of five shots were analyzed periodically from H + 100 to H + 3000 hours Differences in gamma energy spectra were not detectable among samples of different particle size or fallout time from a specific shot, however, differences were detectable among the several shots. The relative abundances of the various gamma energy groups at different times after shot, based on mean values of all samples analyzed per shot, are tabulated in Table 4.1 for Shots Boltzmann, Priscilla, Hood, Diablo, and Shasta Variations in the contributions of the several energy groups among the different shots are evident, particularly in the 1.4 to 1.8 Mev energy range of Shot Hood where relatively high percentage contributions occurred between H + 100 to H + 1000 hours The net effect of percentage fluctuations among the different energy groups is illustrated in Figure 4.16 where mean energy values, derived from Table 4.1, are presented as a function of time after each shot. (The Boltzmann curve nas been omitted due to inability to resolve the high energy component.) The mean energy curves for Shots Priscilla, Diablo, and Shasta are similar, values increased from between 0.49 and 0.58 Mev at H + 100 hours to approximately 0.7 Mev at H + 600 hours and ranged from 0.74 to 0.87 at H + 3000 hours. In contrast, the mean energy of Hood fallout materials was

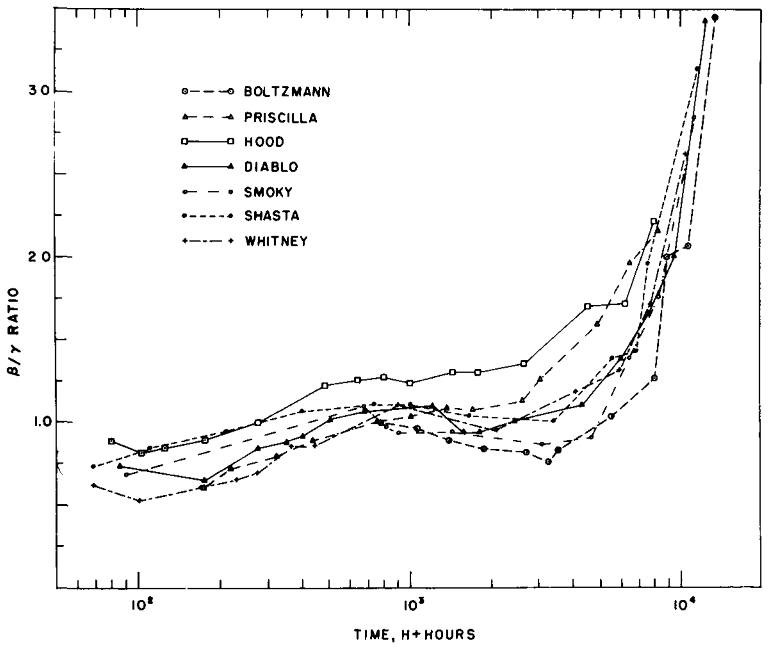


FIGURE 4.15 Comparison of Mean Beta-to-Gamma Ratio Versus Time from Five Tower and Two Balloon Mounted Shots.

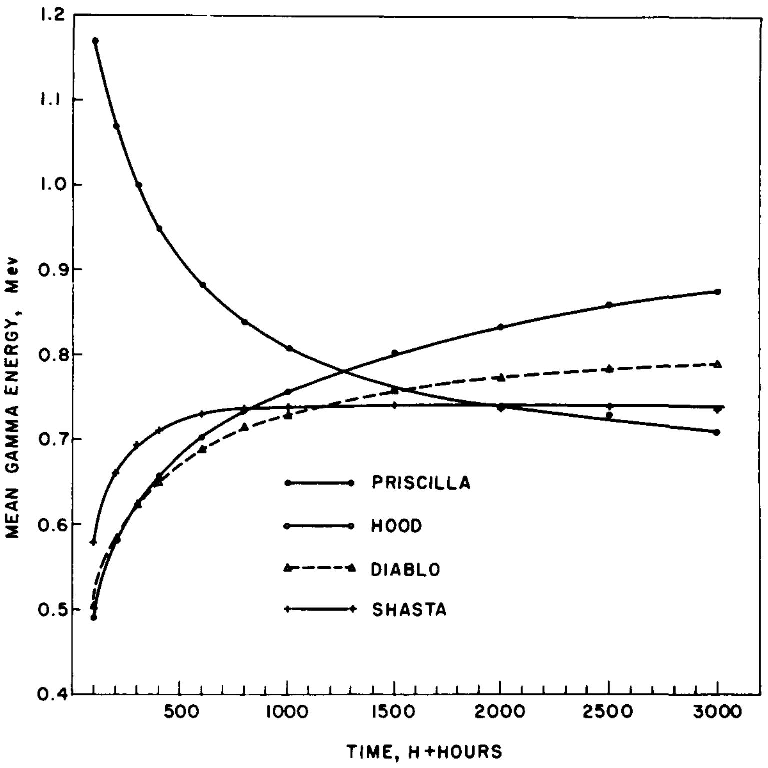


FIGURE 4.16 Mean Gamma Energy of Fallout Samples from Two Tower and Two Balloon Mounted Shots Versus Time After Shot.

TABLE 4 1 Relative Abundance of Gamma Energy Groups Versus Time in Fallout Samples.

Percentages are averages of measurements made on all samples per detonation ND radiation level too low for reliable measurement

Time	Energy Range, Mev						
H + hr	0 1-0 2	0 2-0 3	0 3-0 4	0 4-0 6	0 6-0 7	0 7-0 8	1 4-1 8
	Relative Abundance Pct						
Shot Boltzmann							
300	21 3	8 1	10 4	32 8	ND	19 0	ND
400	21 1	7 6	15 2	32 3	ND	23 9	ND
600	19 9	6 7	11 0	29 8	ND	32 6	ND
800	18 6	5 9	8 3	27 5	ND	39 7	ND
1000	17 5	5 3	6 6	25 4	ND	45 2	ND
1500	15 1	4 2	4 2	21 0	ND	55 6	ND
2000	13 3	3 5	2 8	17 9	ND	62 4	ND
2500	12 1	2 9	2 1	15 5	ND	67 3	ND
3000	11 0	2 9	1 7	13 8	ND	71 1	ND
Shot Priscilla							
100	32 7	ND	16 6	17 3	8 5	16 7	8 5
200	25 9	ND	13 8	20 7	9 5	18 0	12 2
300	22 4	ND	12 1	22 5	9 9	18 4	14 7
400	20 2	ND	10 9	23 6	10 2	18 6	16 6
600	17 4	ND	9 3	24 9	10 3	18 6	19 5
800	15 6	ND	8 3	25 7	10 4	18 4	21 7
1000	14 3	ND	7 5	26 2	10 3	18 2	23 5
1500	12 2	ND	6 2	26 9	10 3	17 7	26 7
2000	11 0	ND	5 4	27 2	10 1	17 2	29 2
2500	10 0	ND	4 9	27 4	9 9	16 7	31 1
3000	9 4	ND	4 4	27 5	9 8	16 3	32 6
Shot Hood							
100	10 1	5 7	ND	14 8	2 2	2 1	65 2
200	11 7	6 2	ND	18 9	3 4	4 5	55 3
300	12 4	6 4	ND	21 4	4 4	7 0	48 5
400	12 7	6 4	ND	23 0	5 2	9 2	43 4
600	12 8	6 3	ND	24 7	6 3	13 5	36 4
800	12 7	6 1	ND	25 6	7 2	17 2	31 3
1000	12 4	5 9	ND	25 9	7 8	20 5	27 5
1500	11 5	5 3	ND	25 7	8 8	27 4	21 2
2000	10 6	4 9	ND	25 0	9 4	33 0	17 2
2500	9 8	4 4	ND	23 9	9 6	37 0	15 5
3000	9 3	4 1	ND	23 3	10 0	41 0	12 3
Shot Diablo							
100	29 4	14 2	15 3	9 9	7 9	12 0	11 3
200	25 4	10 5	12 0	12 6	7 2	18 0	14 3
300	22 9	8 6	10 0	14 0	6 5	22 2	15 8
400	21 0	7 4	8 7	15 0	6 1	25 2	16 7
600	18 2	5 8	6 9	16 0	5 3	30 0	17 8
800	16 3	4 8	5 9	16 7	4 8	33 2	18 4
1000	14 9	4 1	5 1	17 1	4 4	35 8	18 5
1500	12 4	3 1	3 9	17 5	3 7	40 4	18 9
2000	10 8	2 5	3 2	17 5	3 2	43 7	19 0
2500	9 7	2 1	2 7	17 5	2 9	46 2	18 9
3000	8 9	1 8	2 4	17 5	2 6	48 1	18 7
Shot Shasta							
100	13 2	22 1	19 9	8 1	8 4	13 6	14 7
200	14 6	10 8	13 6	11 6	12 6	19 3	17 5
300	14 5	6 6	10 2	13 4	15 2	22 1	18 0
400	14 1	4 5	8 2	14 5	17 0	23 8	18 1
600	13 3	2 5	5 8	15 6	19 3	25 8	17 7
800	12 5	1 7	4 5	16 3	20 9	26 8	17 4
1000	11 9	1 2	3 7	16 9	22 1	27 5	16 8
1500	10 7	0 7	2 5	17 6	24 1	28 5	15 9
2000	9 9	0 4	1 9	18 0	25 6	29 1	15 1
2500	9 3	0 3	1 5	18 3	26 6	29 5	14 5
3000	8 8	0 2	1 3	18 5	27 5	29 7	14 0

approximately twice that of the other shots at H + 100 hours and then decreased to similar values after H + 1200 hours.

4.3.4 Comparison of Dose Calculated by Empirical Plumbbob and $T^{-1.2}$ Decay Curves

If the empirical Plumbbob composite gamma decay curve (Figure 4.11) is assumed to approximate the decline in dose rate, as is assumed in the case of the $T^{-1.2}$ decay curve, a comparison may be made of dosages calculated by the experimental and $T^{-1.2}$ decay curves.

Dosage calculations based on the experimental Plumbbob composite gamma decay curve are necessarily restricted to the time period over which measurements have been completed, in this case 417 days (H + 10,000 hours). Dosages to 417 days calculated on the basis of the experimental curve differ in magnitude from those derived from the $T^{-1.2}$ decay expression depending upon the fallout time. For fallout times of approximately H + 2 to H + 20 hours, dosages determined by the $T^{-1.2}$ expression are lower than those calculated by the Plumbbob composite gamma decay curve from H + 6 to 100 hours. For example, using an initial relative dose rate of ten at a fallout time-of-arrival of H + 2 hours, an infinite dose of 100 would be obtained by the $T^{-1.2}$ curve. However, the dose based on the Plumbbob curve (Figure 4.11) would give an infinite dose larger by a factor of two. The magnitude of difference in dose is illustrated in Table 4.2.

TABLE 4.2 Comparison of Relative Gamma Dose Calculated from Plumbbob Composite Decay Curve and $T^{-1.2}$ Expression.

Based on relative dose rate of ten at fallout time of H + 2 hours giving an infinite dose of 100 by $T^{-1.2}$ decay.

Time Period H + hr	Relative Dose: Plumbbob Decay Curve	Relative Dose: $T^{-1.2}$ Decay Curve	Ratio Plumbbob/$T^{-1.2}$
2-24	76.5	39.1	1.95
2-48	91.5	47.0	1.95
2-720	144.7	69.2	2.09
2-10,000	163.1	81.7	2.00

4.3.5 Implications of Mean Energy Variations

The relatively high mean energy of Hood fallout materials before H + 1000 hours and the general variation in mean energy with time suggest that considerable error can be introduced in the calculation of gamma megacuries from dose rate depending upon the shot and time of measurement. This calculation generally is made on the basis that the uniform contamination of one square mile with fission products having an average energy of 0.7 Mev will result in a radiation field of approximately four r/hr intensity at three feet above the ground surface (Reference 3). The dose rate is approximately proportional to energy, and for example, at H + 100 hours, one gamma megacurie per square mile would have resulted in radiation intensities of about seven r/hr at three feet in Hood, and three r/hr in Diablo and Shasta fallout areas. Gamma megacurie per square mile values calculated on the basis of the four r/hr relationship would consequently have been 75 percent high in the case of the Hood shot and 25 percent low in the case of the Diablo and Shasta shots.

4.4 SUMMARY

1. Differences in slopes of beta radiation decay curves derived from particles of different size and/or fallout time of a specific shot generally differed by less than several tenths of a slope unit over common time periods. Such variation is of the order to be anticipated from the radionuclide content of comparable fallout materials.

2. With the exception of Shot Hood, the beta decay rates of eight tower and balloon mounted shots were similar and approximated a slope of -1.2 to H + 1000 hours with an increase in rate of decay to -1.5 beyond that time. Shot Hood had a negative slope less than one to H + 1000 hours and a slope of approximately -1.7 after that time.

3. The gamma radiation decay rates among the several shots were more variable than corresponding beta decay rates. For time periods earlier than H + 200 hours, the negative slope was less than one. Between H + 200 and H + 700 hours, the decay rate gradually increased and reached a value of -3.0 at H + 10,000 hours. The effect of the deviation in gamma decay rate slopes from -1.2 was to increase the gamma dose calculated from instrument reading by a factor of two.

4. Ratios of beta emission rates to gamma emission rates were similar for individual shots, larger ratios were associated with smaller particle size. Balloon shot ratios were generally greater than those for tower shots.

5. In all shots but Hood, the mean gamma energy was approximately 0 5 Mev at H + 100 hours, then increased to 0.70 Mev at H + 600 hours and ranged from 0.74 to 0.87 at H + 3000 hours. The mean gamma energy for Hood samples was 1.17 Mev at H + 100 hours followed by a decrease to the same range as other shots.

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CHAPTER 5

CERTAIN PHYSICAL AND CHEMICAL PROPERTIES OF FALLOUT DEBRIS

5.1 INTRODUCTION

In this fourth phase of fallout pattern characterization, the data on the physical, chemical and radiochemical characteristics of fallout debris furnish a basis for comparing the relative significance of the fallout of balloon and tower mounted shots. The data may also be correlated with levels of the specified radionuclides in the tissues of native and some domestic animals, together with the distribution of these isotopes on or in the tissues of native plants.

5.2 PROCEDURES

The procedures used for these characteristic studies are given in detail in Appendix A, Sections A.3.3, A.3.4, and A.3.5.

5.3 RESULTS

Differences in magnetic, solubility, and radiochemical properties were primarily associated with differences in particle size, thus fallout materials from each shot having the same size range but different fallout times had similar properties, as did fallout material of different size fractions greater than 88 microns (or in some cases, less than 44 microns) in diameter. Consequently, the data reported in succeeding sections of this chapter represent mean values based on individual analyses of samples included in the particle size ranges indicated. The standard deviation figures refer to the distribution of individual cases about the mean. Results of the analysis of individual samples are tabulated in Appendices D and E.

5.3.1 Magnetic Properties

The magnetic characteristics of particles of different size fractions from the Boltzmann, Priscilla, Hood, Diablo, Shasta, and Smoky shots were determined as described in Appendix A. The individual sample results are reported in Appendix E and are summarized in Table 5.1.

Fallout materials of all sizes collected from balloon mounted Shots Hood and Priscilla were essentially nonmagnetic. The magnetic fraction of tower shot fallout material greater than 44 microns in diameter ranged, on the average, from 56 to 84 percent. The magnetic fraction of tower shot fallout less than 44 microns in diameter varied from 6 to 12 percent with the exception of Shot Smoky, where the magnetic fraction of the less than 44 micron fraction averaged 46 percent.

The very low percentages of magnetic fraction of the balloon shot fallout when compared to high percentage of tower shot fallout suggests that a significant iron content was derived from tower material, particularly in the larger particle sizes. The contribution of iron from soil materials to the magnetic fraction of fallout apparently was minimal according to measurements made on fallout debris from Shot Priscilla. Its fireball was reported to have not quite intersected the soil surface. Also, it is apparent from these results that this method of analysis will not provide data that permit estimates of how much tower material was vaporized and incorporated in fallout debris.

TABLE 5.1. Beta Activity Magnetically Separated from Fallout Material

	Particle Size Range, Microns	Magnetic Fraction, Pct of Total Beta Activity
Tower Mounted		
Boltzmann	44-300	77.0 ± 4.2
	<44	11.9 ± 5.0
Shasta	44-210	56.1 ± 17.0
	<44	9.2 ± 6.7
Diablo	44-125	80.2 ± 7.2
	<44	6.4 ± 2.8
Smoky	88-250	83.6 ± 8.7
	44-88	80.7 ± 8.0
	<44	46.3 ± 5.5
Balloon Mounted		
Priscilla	<500	<0.2
Hood	<44	<0.1

5.3.2 Solubility

The data concerning the solubility of fallout material derived from Shots Boltzmann, Priscilla, Hood, Diablo, Shasta, and Smoky are given in Appendix E, Table E.2.

5.3.2.1 Solubility Rates

The results of successive one hour water extractions of Priscilla and the magnetic fraction of Diablo fallout size fractions appear in Figure 5.1. The shapes of the Priscilla curves indicate that the cumulative solubility approached its maximum after the fourth extraction The total solubility of fallout debris obtained after the fourth extraction ranged from 45 to 90 percent depending upon the particle size, of those obtained with a single one hour extraction Successive extractions were least effective in removing additional radioactivity from smaller particles, or, in other words the initial extraction removed a greater percentage of the total extractable radioactivity of small particles than of larger particles

The corresponding curves for successive one hour water extractions of Diablo fallout size fractions are more variable in shape, which was probably a result of the low solubility percentages involved (less than 0 6 percent of the total beta activity after the fourth extraction) Cummulative total solubility of fallout debris obtained with the fourth extraction ranged from 20 to 96 percent of those obtained with the single extraction, a range which is not greatly different from those observed with Priscilla samples

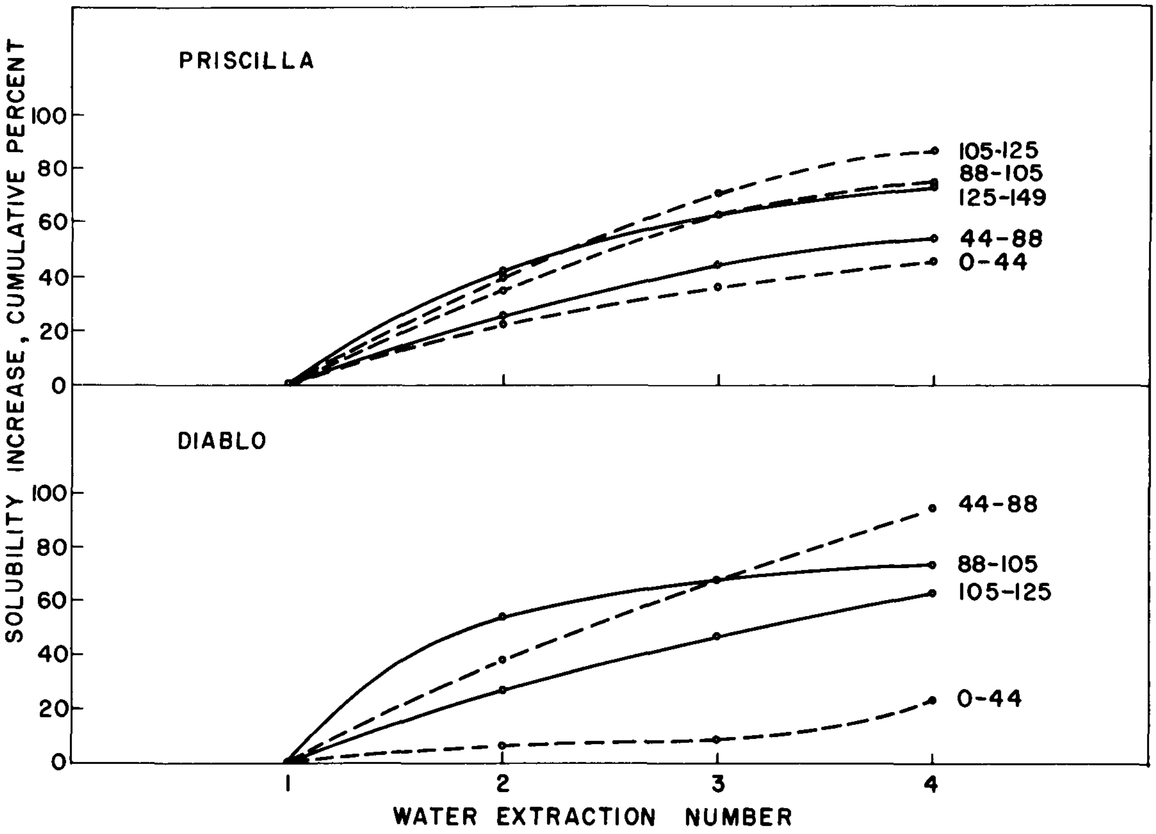


Figure 5.1 Cumulative Increase in Water Solubility of Selected Priscilla and Diablo Fallout Samples as a Function of the Number of Extractions.

The results of successive 0 1 N HCl one hour extractions of Priscilla and Diablo fallout size fractions are presented in Figure 5 2 The shapes of the Priscilla curves indicate that the cumulative solubility was more complete with the fourth acid extraction than with the fourth water extraction The cumulative solubility of fallout debris obtained after the fourth extraction of Priscilla particles ranged from 10 to 22 percent of those obtained with a single extraction

The acid-extraction curves of Diablo fallout materials are similar to the water-extraction curves in that the cumulative solubility of fallout debris ranged from 48 to 90 percent of those obtained with a single extraction The shapes of the curves suggest that, in some cases, continued extraction would have yielded solubility in excess of 100 percent of those obtained with a single extraction Trends of the effect of particle size on extractability are not apparent

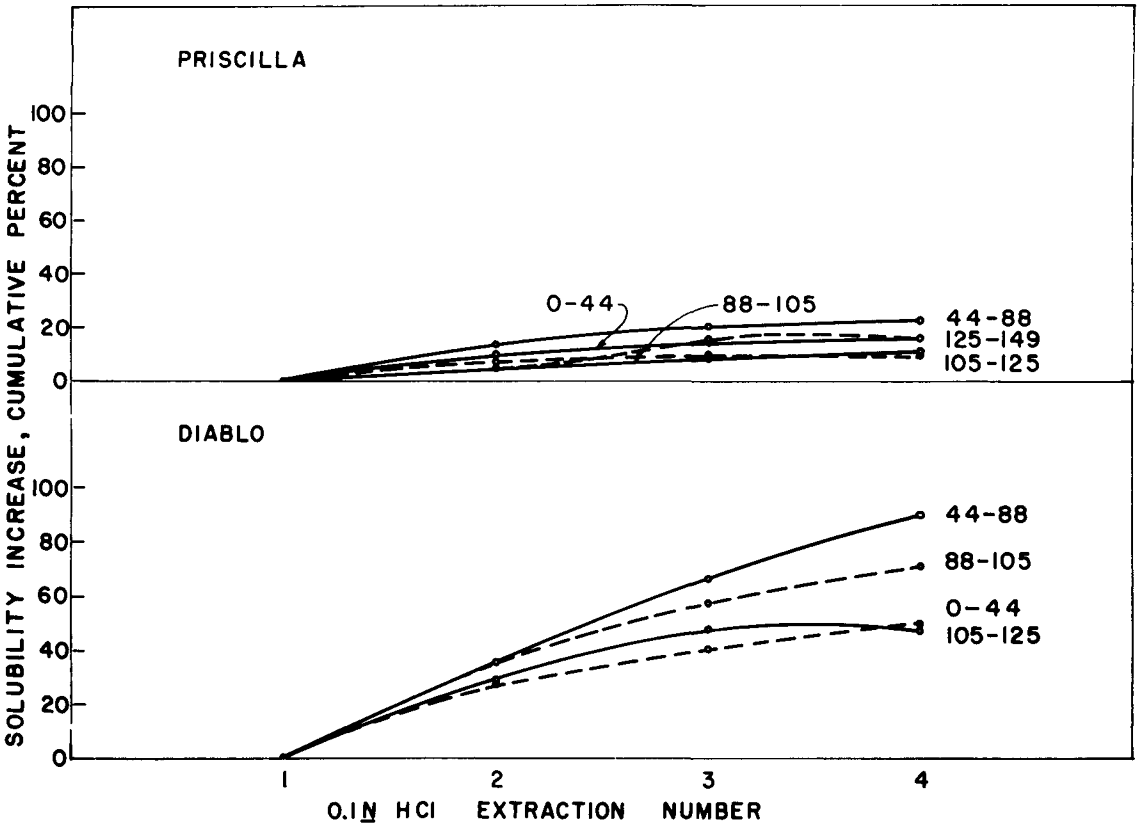


Figure 5.2 Cumulative Increase in HCl solubility of Selected Priscilla and Diablo Fallout Samples as a Function of the Number of Extractions.

5. 3. 2. 2 Solubility of Magnetic versus Nonmagnetic Fractions

Measurements of solubility percentages of magnetic and nonmagnetic fractions of Shasta, Diablo, and Smoky fallout are summarized in Table 5. 2. The data indicate that nonmagnetic fallout was 3 to 10 times more soluble in water and 1. 3 to 3 times more soluble in 0. 1 N HCl than was magnetic fallout.

TABLE 5. 2 Solubility of Magnetic and Nonmagnetic Fallout from Tower Mounted Shots

Shot	Particle Size Range, Microns	Solubility Pct of Beta Activity: Magnetic H_2O	Solubility Pct of Beta Activity: Magnetic 0. 1 N HCl	Solubility Pct of Beta Activity: Nonmagnetic H_2O	Solubility Pct of Beta Activity: Nonmagnetic 0. 1 N HCl
Shasta	44-210	0. 08 ± 0. 05	3. 0 ± 0. 9	0. 4 ± 0. 1	6. 7 ± 1. 0
	< 44	0. 03 ± 0. 1	6. 9 ± 0. 2	1. 8 ± 0. 2	22. 6 ± 3. 1
Diablo	44-125	0. 2 ± 0. 1	3. 0 ± 0. 7	1. 1 ± 0. 4	8. 2 ± 1. 8
	< 44	0. 5 ± 0. 1	7. 1 ± 1. 5	1. 7 ± 0. 6	14. 6 ± 2. 5
Smoky	88-250	0. 2 ± 0. 05	19. 2 ± 1. 6	1. 2 ± 0. 4	25. 7 ± 4. 2
	44- 88	0. 3 ± 0. 05	24. 4 ± 5. 3	3. 3 ± 0. 7	43. 1 ± 5. 0
	< 44	1. 0 ± 0. 02	29. 9 ± 2. 9	2. 8 ± 0. 5	41. 8 ± 3. 0

5.3.2.3 Solubility of Tower and Balloon supported Shot Fallout

The net solubility percentages of different size fractions of fallout from Shots Priscilla, Hood, Boltzmann, Shasta, Diablo, and Smoky, after accounting for the different solubilities of magnetic and nonmagnetic components, are summarized in Table 5.3.

TABLE 5.3 Solubility of Fallout from Tower and Balloon Mounted Shots

Shot	Particle Size Fractions, Microns	Solubility, Pct of Beta Activity	
		H_2O	0.1 N HCl
Balloon mounted			
Priscilla	297-500	31.3 ±1.2	99.2 ± 3.8
	<297	14.2 ±3.0	65.9 ± 4.5
Hood	< 44	14.5 ±2.3	61.8 ± 4.4
Tower mounted			
Boltzmann[a]	44-300	0.4 ±0.2	5.0 ± 1.2
	< 44	1.2 ±0.4	35.1 ± 8.1
Shasta	44-210	0.2 ±0.1	4.6 ± 0.8
	< 44	1.7 ±0.2	21.1 ± 3.1
Diablo	44-125	0.4 ±0.2	4.0 ± 0.9
	< 44	1.6 ±0.6	14.0 ± 2.4
Smoky	88-250	0.4 ±0.2	20.3 ± 2.0
	44- 88	0.9 ±0.2	28.0 ± 5.3
	< 44	2.0 ±0.4	36.3 ± 3.0

[a] Based on magnetic fallout only.

The data indicate the following observations:

(1) The solubility of tower shot fallout tended to increase with decreasing particle size while the opposite was true of balloon shot fallout

(2) The solubility of tower shot fallout in water was 2 percent or less, depending upon the particle size, the water solubility of balloon shot fallout was approximately 14 percent for the less than 44 micron size fraction, the predominant size

(3) The solubility of tower shot fallout in 0.1 N HCl was approximately 5 percent for particle sizes greater than 44 microns with the exception of the Smoky fallout which averaged 24 percent solubility in acid. The acid solubility of less than 44 micron fraction tower shot fallout was more variable and ranged between 14 and 36 percent. The acid solubility of balloon shot fallout was of the order of 65 percent for its predominant particle size, less than 44 micron fraction.

5.3.3 Analysis of Fallout Samples for Seven Radionuclides

Samples of different particle sizes derived from the tower mounted Shots Boltzmann, Diablo, Shasta, and Smoky and the Priscilla balloon shot were analyzed for radionuclides of barium, cerium, cesium, ruthenium, strontium, yttrium, and zirconium. The results are reported in terms of percentage of total beta activity at D + 30 days.

Values for specific radioelements were extrapolated from date of analysis to D + 30 days on the basis of experimentally determined decay values. Based upon the experimental decay curves and published values of decay rates, Ba^{140}, Cs^{136}, Sr^{89}, Y^{91}, and Zr^{95} were determined to represent approximately 100 percent of the respective radioelement percentages at D + 30 days. The experimental decay curves of separated cerium and ruthenium indicated that mixtures of these radionuclides were involved in both cases.

Similarities in radioelement percentages were generally observed for particle sizes greater than 88 microns in diameter for individual shots. Consequently, the primary data tabulated in Appendix D have been summarized in succeeding sections in terms of the less than 5 (where analyzed), less than 44, 44-88, and greater than 88 micron size fractions.

5.3.3.1 Radionuclide Analyses of Fallout from Four Tower Shots and Priscilla

The results of radionuclide analyses of tower shot (Boltzmann, Diablo, Shasta, and Smoky) fallout samples are presented in Table 5.4. Fractionation trends with respect to particle size were frequently not certain due to the magnitudes of standard deviation values. However, based on mean values, the data indicate the following observations:

(1) All shots except Boltzmann demonstrated increasing Ba^{140} percentages with decreasing particle size. The average Ba^{140} percentages of the less than 44 micron and the less than 5 micron size fractions were larger than those of the greater than 88 micron material by as much as 22 percent (Smoky) and 50 percent (Smoky, Shasta), respectively.

(2) The average Ce^{141}+Ce-Pr^{144} percentages tended to decrease with decreasing particle size; Ce^{141}+Ce-Pr^{144} percentages of the less than 44 micron fraction were as much as 20 percent (Boltzmann, Smoky) less than those of greater than 88 micron fraction.

(3) The Cs^{136} percentages were of the order of 0.2 percent, but extremely low values precluded further analysis.

(4) Radioruthenium values demonstrated the greatest percentage differences among the several tower shots: the Boltzmann $Ru^{103,106}$ percentages were approximately three times greater than those of corresponding particle sizes of the other shots. The $Ru^{103,106}$ percentages tended to increase with decreasing particle size; the less than 44 micron percentages were 50 to 130 percent more than those of the greater than 88 micron material (Smoky, Diablo, Shasta).

(5) $Strontium^{89,90}$ percentages were of the same order of magnitude as those of $Ru^{103,106}$ and demonstrated similar fractionation in favor of the smaller particle sizes. The less than 44 micron fraction percentages were approximately 85 percent more than those of greater than 88 micron material. The $Sr^{89,90}$ percentages of the less than 5 micron fraction were approximately 15 percent more than those of the less than 44 micron fraction of which it is a part.

TABLE 5.4 Radionuclide Content of Fallout Material According to Particle Size Fractions

NS, not significant at time of analysis

	Boltzmann	Diablo	Shasta	Smoky	Priscilla
Particle size, microns	88-149	88-350	88-500	88-1000	88-500
No. of samples used for mean	3	11-12	38-54	37-43	12-14
Radionuclide, Pct of sample beta activity, D + 30 days					
Ba^{140}	15.5 ± 1.8	12.9 ± 1.1	13.0 ± 2.7	11.7 ± 2.6	17.7 + 1.8
Ce^{141} + $Ce\text{-}Pr^{144}$	20.9 ± 1.0	17.2 ± 2.8	15.9 ± 2.5	19.4 ± 3.1	16.5 ± 1.9
Cs^{136}	0.24 ± 0.05	0.15 + 0.03	NS	NS	0.08 ± 0.01
$Ru^{103,106}$	5.2 ± 3.2	1.5 ± 0.2	1.2 ± 0.4	1.3 + 0.5	7.2 ± 3.3
$Sr^{89,90}$	1.7 0.47	1.3 ± 0.2	1.3 ± 0.4	1.3 ± 0.4	2.8 + 0.3
Y^{91}	9.9 ± 1.1	9.9 ± 1.3	9.6 ± 1.3	10.3 + 1.0	14.7 ± 2.1
Zr^{95}	8.7 ± 1.6	9.0 ± 1.8	7.4 ± 1.2	7.6 ± 0.7	3.8 + 1.3
Pct of total beta activity (Σ)	62	52	49	52	63
Particle size, microns	44-88	44-88	44-88	44-88	44-88
No. of samples used for mean	1	4	10-13	6	5
Radionuclide, Pct of sample beta activity, D + 30 days					
Ba^{140}	14.5	13.1 ± 1.1	12.6 ± 1.3	11.8 ± 1.0	17.3 ± 1.8
Ce^{141} + $Ce\text{-}Pr^{144}$	17.7	18.6 ± 5.1	16.9 ± 1.8	18.9 + 4.0	13.1 ± 1.5
Cs^{136}	0.24	0.16 ± 0.04	NS	NS	0.05 ± 0.03
$Ru^{103,106}$	3.4	1.6 ± 0.3	1.5 ± 0.2	1.3 ± 0.3	9.4 ± 2.7
$Sr^{89,90}$	1.6	1.5 ± 0.2	1.2 ± 0.2	1.5 ± 0.3	3.8 ± 1.2
Y^{91}	9.1	10.6 ± 1.4	9.2 ± 1.1	10.7 ± 0.8	13.7 ± 4.5
Zr^{95}	9.1	9.1 ± 2.2	7.4 ± 1.0	6.7 + 1.0	3.8 ± 0.6
Pct of total beta activity (Σ)	56	55	49	51	61
Particle size, microns	<44	<44	<44	<44	<44
No. of samples used for mean	3	4	11-15	6	6
Radionuclide, Pct of sample beta activity, D + 30 days					
Ba^{140}	15.1 ± 0.5	14.6 ± 0.8	14.9 ± 1.5	14.3 ± 1.1	18.6 ± 1.9
Ce^{141} + $Ce\text{-}Pr^{144}$	16.8 ± 1.4	17.2 ± 2.4	14.9 ± 1.9	16.2 + 1.0	13.4 ± 2.4
Cs^{136}	0.23 ± 0.03	0.16 ± 0.01	NS	NS	0.11 ± 0.03
$Ru^{103,106}$	6.7 ± 1.5	2.8 ± 0.3	2.8 ± 0.5	2.0 ± 0.3	11.0 ± 1.7
$Sr^{89,90}$	2.8 + 1.0	2.4 ± 0.2	2.4 ± 0.5	2.7 ± 0.3	6.4 ± 0.6
Y^{91}	10.3 ± 0.7	11.5 ± 0.6	11.0 ± 1.0	13.1 ± 1.6	13.5 ± 2.3
Zr^{95}	8.0 ± 0.2	7.9 ± 0.9	6.4 ± 0.9	6.3 ± 0.8	4.2 ± 0.4
Pct of total beta activity (Σ)	60	56	52	55	67
Particle size, microns	5	<5	<5	<5	<5
No. of samples used for mean	0	0	4-6	4-6	0
Radionuclide, Pct of sample beta activity, D + 30 days					
Ba^{140}	--	--	19.8	17.3 ± 5.0	--
Ce^{141} + $Ce\text{-}Pr^{144}$	--	--	14.1 ± 2.9	16.5 ± 2.7	--
Cs^{136}	--	--	NS	NS	--
$Ru^{103,106}$	--	--	2.4 ± 0.9	1.5 ± 0.2	--
$Sr^{89,90}$	--	--	2.8 ± 0.4	3.1 ± 0.3	-
Y^{91}	--	--	10.6 ± 2.3	11.8 ± 2.6	--
Zr^{95}	--	--	6.6 ± 0.3	6.4 ± 0.5	--
Pct of total beta activity (Σ)	--	--	56	57	--

(6) The Y^{91} percentages increased with decreasing particle size in all cases but to quite different degrees. The $Sr^{89,90}$ percentages of the less than 44 micron fraction were more than those of the greater than 88 micron fraction by 4 to 27 percent.

(7) The Zr^{95} percentages decreased with decreasing particle size; the percentages of the less than 44 micron size fraction, 10 to 15 percent, were lower than those of the greater than 88 micron fallout material.

Radionuclide percentages from the balloon mounted Shot Priscilla are also presented in Table 5.4.

The Priscilla radionuclide percentages of Ba^{140}, $Ru^{103,106}$, Sr^{89}, and Ce^{141}+ Ce-Pr^{144} indicated the same trends of fractionation with respect to particle size as those described above for tower shots. The Ba^{140}, $Ru^{103,106}$, and Sr^{89} percentages of the less than 44 micron size fraction were 5, 53, and 129 percent, respectively, more than those of the greater than 88 micron fraction. The Ce^{141}+ Ce-Pr^{144} percent of the less than 44 micron fraction was 23 percent lower than that of the largest size group. The Y^{91} and Zr^{95} demonstrated slight fractionation trends opposite to those of tower shots.

Selected particle size fractions, previously analyzed for $Sr^{89,90}$ (total radiostrontium), from various locations within the Diablo, Shasta, and Smoky fallout patterns were analyzed for Sr^{90} content approximately one year following the conclusion of the Plumbbob Test Series. The results of these analyses appear in Table 5.5 in terms of Sr^{90} percentages of total radiostrontium and total beta activity at D + 30 days.

TABLE 5.5 Percentages of Total Radiostrontium and of Total Beta Activity at D + 30 Days.

Size Fraction, Microns	No of Sr^{90} Samples	Pct Sr^{90} of Total Radiostrontium	Pct of Total Beta Activity	
			Total Sr Activity[a]	Sr^{90}
Shot Diablo				
88-500	13	2.7 ± 0.55	1.3 ± 0.16	0.035
44- 88	4	1.7 ± 0.35	1.5 ± 0.20	0.026
< 44	8	2.0 ± 0.61	2.4 ± 0.20	0.048
Shot Shasta				
88-500	6	3.4 ± 1.15	1.3 ± 0.35	0.044
44- 88	7	3.1 ± 0.67	1.2 ± 0.23	0.037
< 44	10	2.0 ± 0.49	2.4 ± 0.50	0.048
Shot Smoky				
88-210	4	2.6 ± 0.85	1.3 ± 0.36	0.034
44- 88	5	3.1 ± 1.3	1.5 ± 0.27	0.047
< 44	6	3.4 ± 1.6	2.7 ± 0.32	0.092
< 5	5	3.5 ± 1.6	3.1 ± 0.27	0.11

[a] Mean values from Table 5.4

Fractionation of Sr^{90} with respect to particle size was not detectable with the possible exception of Smoky samples where mean Sr^{90} percentages of total beta activity increased as particle size decreased. Strontium ^{90} percentages of total radiostrontium, however, are associated with relatively high standard deviation values; and fractionation trends with respect to particle size are more reliably indicated for total radiostrontium, which was primarily Sr^{89} at D + 30 days.

5.3.3.2 Tower versus Balloon Shot Radionuclide Percentages

Similar percentage values for specific radionuclides among the same size fractions of the different tower shots permit the determination of mean percentage values descriptive of tower shots in general. These values, derived from the data appearing in Table 5.4 are presented in Figure 5.3 in conjunction with the radionuclide percentages of Priscilla fallout samples.

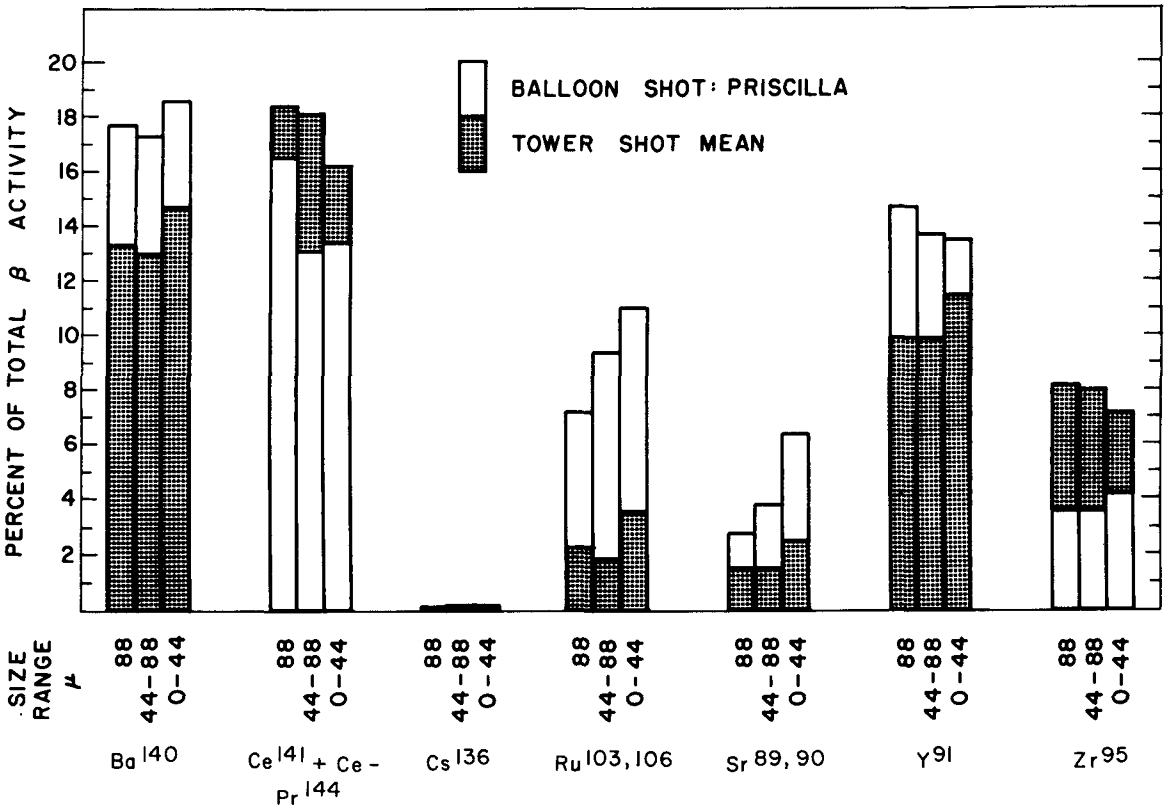


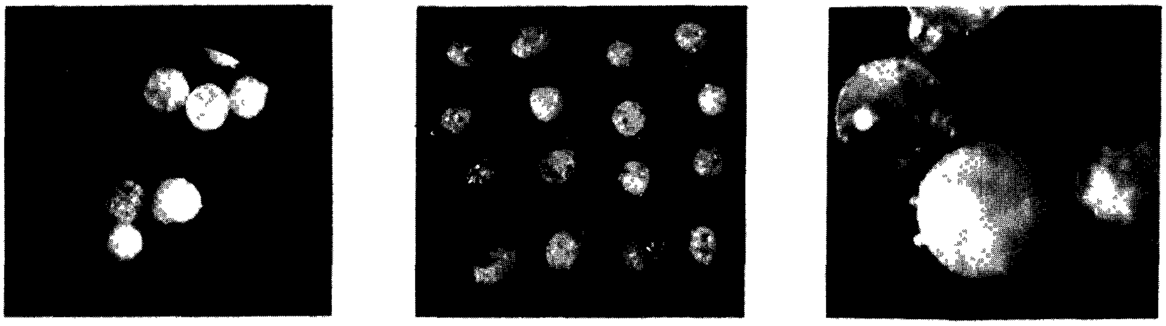
Figure 5.3 Comparison of Radionuclide Percentages of Different Particle Size Fractions of Tower and Balloon Shot Fallout.

The comparison of mean tower shot percentages to those of Shot Priscilla indicates that for corresponding size fractions: Priscilla radionuclide percentages were approximately 30 percent higher for Ba^{140}; 11 to 38 percent higher for Ce^{141}+Ce-Pr^{144}; 300

to 400 percent higher for $Ru^{103, 106}$; 250 percent higher for Sr^{89}; 20 to 50 percent higher for Y^{91}; and 50 percent lower for Zr^{95} than the corresponding percentages of tower shots.

5.3.4 Physical Characteristics

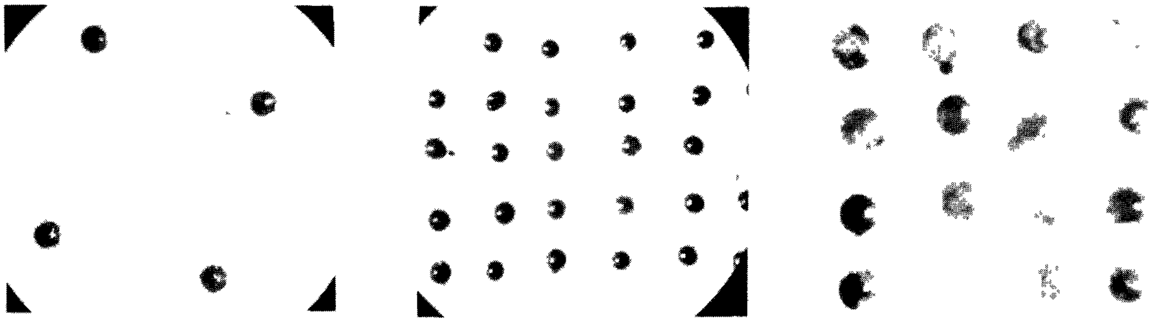
The shape of all fallout particles observed tended to be spherical with frequent protrusions. Examples of particles larger than 88 microns in diameter from Shots Hood, Priscilla, Diablo, and Shasta appear in Figure 5.4. Examples of particles less than 44 microns in diameter from the Boltzmann shot appear in Figure 5.5 in conjunction with ground zero soil material of the same size fraction. Spherical particles as small as several microns in diameter were detectable in contrast to the predominantly angular particles of ground zero soil.



BALLOON (HOOD), 350-500 u
TRANSLUSCENT

BALLOON (HOOD), 350-500 u
TRANSLUSCENT

BALLOON (PRISCILLA), 350-500 u
TRANSLUSCENT



TOWER (DIABLO), 105-125 u
OPAQUE

TOWER (SHASTA), 88-105 u
OPAQUE

TOWER (SHASTA), 105-125 u
TRANSLUSCENT

Figure 5.4 Examples of Translucent and Opaque Fallout Particles from Tower and Balloon Shots.

Particles orginating from Shots Diablo and Shasta demonstrated two general appearance groups; those which were opaque and those which were transparent or translucent (Figure 5.4). Opaque particles varied in color from black to dark red with smooth, highly vitreous to rough, lusterless surfaces. Transparent and translucent particles were generally colorless with smooth, vitreous surfaces. These particles generally contained large numbers of internal bubbles.

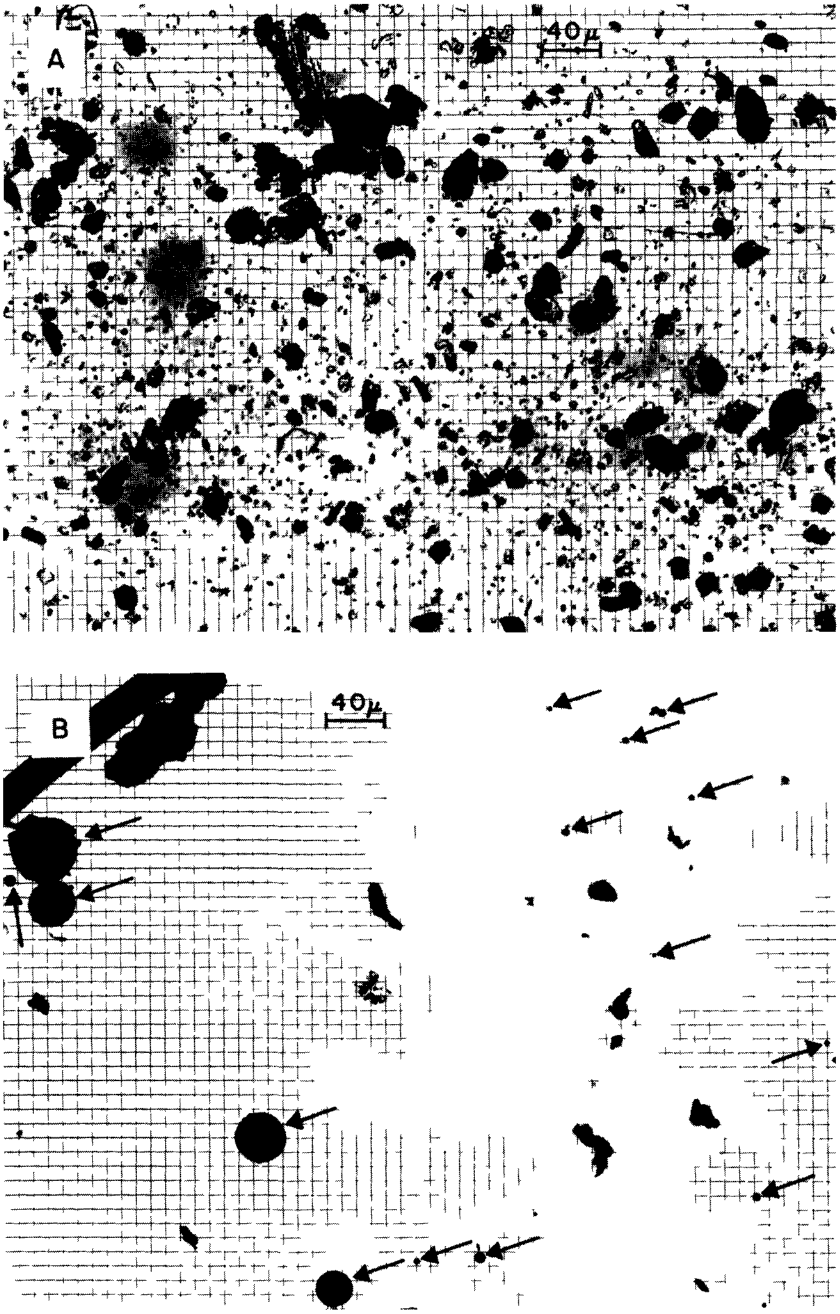


Figure 5.5 Particles less than 44 microns in Boltzmann surface ground zero soil (A) and Boltzmann fallout samples (B) from about 80 miles from ground zero. One grid unit equivalent to ten microns. (Photographs by LRL).

The distribution of the various types of opaque as well as transparent particles was determined for a Diablo fallout area by classifying all particles in successive microscope fields. The results appear in Table 5.6. Opaque particles comprised 70 percent or more of the total number of radioactive particles. The predominance of opaque particles in tower shot fallout materials in general was estimated by a less precise inspection of samples from other tower shots.

TABLE 5.6 Particle Distribution According to Appearance and Size

Particles collected at GC Station 14.2 miles from ground zero, 5.8 miles east of midline, Shot Diablo

Particle Appearance	Particle Size Range, microns 1000-500	500-350	350-297	297-250	250-210	210-177	177-149	149-125	125-105	105-88	88-44
	Pct of Number of Particles Observed per Size Range										
Opaque											
black, rough	31.1	62.1	67.4	48.6	44.3	38.2	58.3	42.0	44.1	62.6	42.0
black, smooth	23.4	0.0	17.4	14.9	9.8	16.7	15.3	11.5	12.5	10.5	21.7
dark red	33.8	32.2	13.0	33.8	31.2	23.5	19.4	16.0	26.5	23.4	26.1
SUBTOTAL	88.3	94.3	97.8	97.3	85.3	78.4	93.0	69.5	83.1	96.5	89.8
Transparent	1.3	3.4	0.0	0.0	9.8	6.9	1.4	13.5	9.3	0.6	5.8
Other	10.4	2.3	2.2	2.7	4.9	14.7	5.6	17.0	7.6	2.9	4.4

In contrast to tower shot fallout, inspection of fallout materials derived from the balloon mounted Shots Priscilla and Hood indicated that transparent or translucent particles comprised virtually 100 percent of the particles present (Figure 5.4). The particles were generally characterized by internal gas bubbles.

5.3.5 Specific Activity per Particle

The different types of opaque particles and transparent particles collected at different locations within the Diablo and Shasta fallout patterns were isolated and analyzed for beta radioactivity. The particles were analyzed in groups and values of the mean activity per particle were determined. The mean values, thus obtained, were variable; and no consistent relationships were observed among the different types of opaque particles or with respect to fallout time-of-arrival. However, differences were detected between the opaque particles as a group and the transparent particles. Table 5.7 summarizes the results of analysis of the two types of particles as a function of particle size for particles produced by Shots Diablo and Shasta. The mean values presented are weighted on the basis of the number of particles per particle group.

The values of the mean radioactivity per particle of opaque Diablo particles do not demonstrate a definitive reduction with particle size, with the possible exception of the 44-88 micron size fraction. Particle sizes from 2000 to 88 microns averaged 1.06 microcuries per particle at H + 12 hours and the 44-88 micron size range averaged 0.31 microcuries per particle at H + 12 hours. Transparent particles averaged 0.19 microcuries per particle or approximately 20 percent of the particle activities of opaque particles.

Opaque Shasta particles in the size range of 250 to 44 microns averaged 0.49 μc per particle at H + 12 hours. Transparent particles averaged 0.17 μc per particle or approximately 35 percent of the particle activities of opaque particles.

TABLE 5.7 Radioactivity Per Particle of Different Particle Size Fractions

Size Fraction Microns	Total No. of Particles	No. of Particle Groups	Beta μc/particle, H + 12 hours	
			Range	Mean
Shot Diablo: Opaque Particles				
2000-1000	40	4	0.527-0.994	0.832
1000- 500	29	3	1.056-1.372	1.18
500- 350	20	2	0.846-1.018	0.932
350- 297	16	3	0.736-1.469	1.301
297- 250	23	3	0.850-1.629	1.292
250- 210	22	3	1.029-1.091	1.064
210 177	28	3	0.891-1.013	0.943
177- 149	23	5	0.319-1.170	0.786
149- 125	49	9	0.155-1.062	0.695
125- 105	77	14	0.086-2.941	1.18
105- 88	72	8	0.623-2.228	1.43
88- 44	58	6	0.122-0.613	0.306
Shot Diablo: Transparent Particles				
2000-1000	8	1	0.258	0.258
1000- 500	1	1	--	0.051
250- 210	2	1	0.143	0.143
210- 177	3	1	0.0163	0.016
177- 149	1	1	--	0.232
149- 125	13	2	0.0505-0.233	0.205
125- 105	20	2	0.140 -0.567	0.354
105- 88	2	1	0.382	0.382
88- 44	11	1	0.0452	0.045
Shot Shasta: Opaque Particles				
250-210	12	1	--	0.370
210-177	26	4	0.230-1.69	0.506
177-149	52	2	0.560-0.579	0.570
149-125	55	3	0.335-0.549	0.483
125-105	129	7	0.260-1.45	0.517
105- 88	617	14	0.313-0.965	0.585
88- 44	4751	24	0.163-0.706	0.400
Shot Shasta: Transparent Particles				
149-125	63	1	--	0.176
125-105	34	3	0.101-0.304	0.243
105- 88	213	5	0.112-0.244	0.176
88- 44	526	7	0.075-0.146	0.099

5.4 DISCUSSION

5.4.1 Comparison of Deposition of Soluble Radionuclides by Shots Priscilla and Smoky

The net effect of differential fallout levels, degree of solubility, and radionuclide percentages of tower and balloon shot fallout upon potential biological availability at different fallout times may be estimated on the basis of values reported in previous sections of this chapter.

Shots Smoky and Priscilla are most appropriate for comparison of the two types of detonation since they were detonated at the same height and had similar yields. The comparison can be further simplified by considering only the less than 44 micron size fraction on the basis that this particle size is the most widely distributed and potentially the most important with respect to biological accumulation.

In the case of equal radioactivity levels of the less than 44 micron Smoky and Priscilla fallout, approximations of the relative amounts of radionuclides of barium, cerium, ruthenium, strontium, yttrium, and zirconium, as of D + 30 days, in the original, acid-soluble and water-soluble forms may be obtained by multiplying the solubility percentages of Table 5.3 by the radionuclide percentages of Table 5.4. This treatment of these data assumes minimal radioelement fractionation among the initial or untreated fallout and water and acid extracts. The results are illustrated in Figure 5.6. The calculated values indicate that acid-soluble radionuclides derived from the Priscilla less than 44 micron fallout exceed those from Smoky by factors ranging from slightly in excess of 1 to approximately 10. Water-soluble radioelements derived from Priscilla fallout exceed those from Smoky by factors ranging from approximately 5 to 40.

Where equal radioactivity levels of the less than 44 micron fallout are considered, the greater amounts of soluble radionuclides derived from Priscilla fallout in comparison to those from Smoky, are opposed by higher fallout levels from Shot Smoky at different fallout times. The integrated total and the less than 44 micron fallout levels presented for the two shots in Figure 3.14 are compared in Figure 5.7 in terms of ratios of Smoky and Priscilla fallout as a function of fallout time. The levels of fallout of all sizes from Shot Smoky exceeded those from Shot Priscilla by factors in excess of 20 for fallout times-of-arrival up to 15 hours; the levels of less than 44 micron fallout from Shot Smoky exceeded those from Shot Priscilla by factors of approximately 8 to 13.

Based on the ratios appearing in Figures 5.6 and 5.7, the relative levels of the various radionuclides in the initial or untreated form, and in the acid- and water-soluble forms derived from the less than 44 micron Smoky and Priscilla fallout can be estimated for the various fallout times. Examples of such calculations appear in Figures 5.8 and 5.9 for Ba^{140} and Sr^{89}, respectively. The amounts of total Ba^{140} and Sr^{89}, and acid-soluble Ba^{140} and Sr^{89} to a less degree, derived from Smoky less than 44 micron fallout considerably exceed those from Shot Priscilla over the 1 to 15 hour fallout time period. However, the amounts of water-soluble Ba^{140} derived from Shot Smoky only slightly

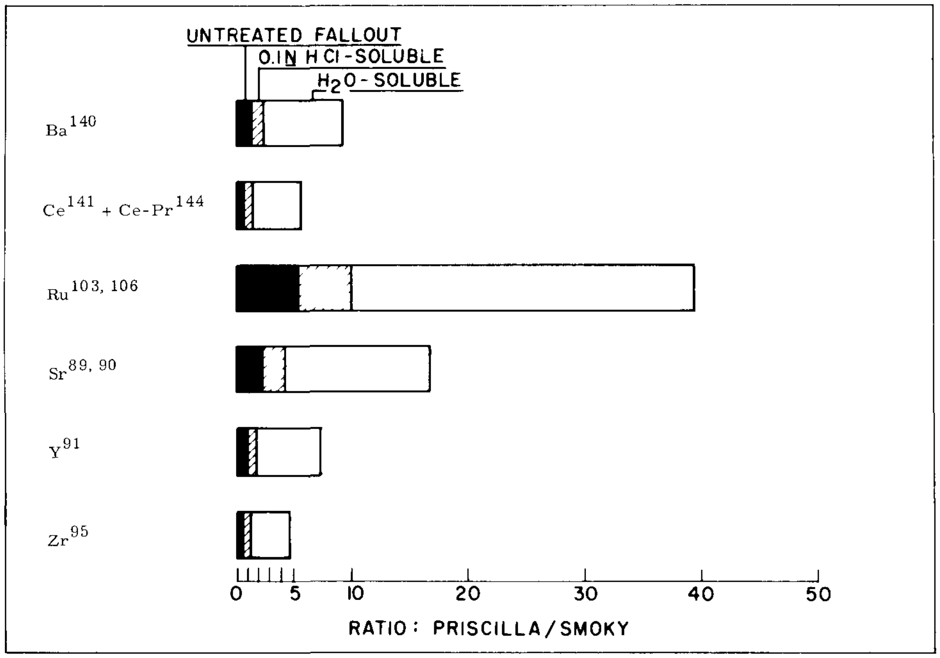


Figure 5.6 Priscilla-to-Smoky Radionuclide Ratios (D + 30 days) in Untreated, Acid-Soluble, and Water-Soluble Fractions of Less Than 44 Micron Diameter Fallout Particles.

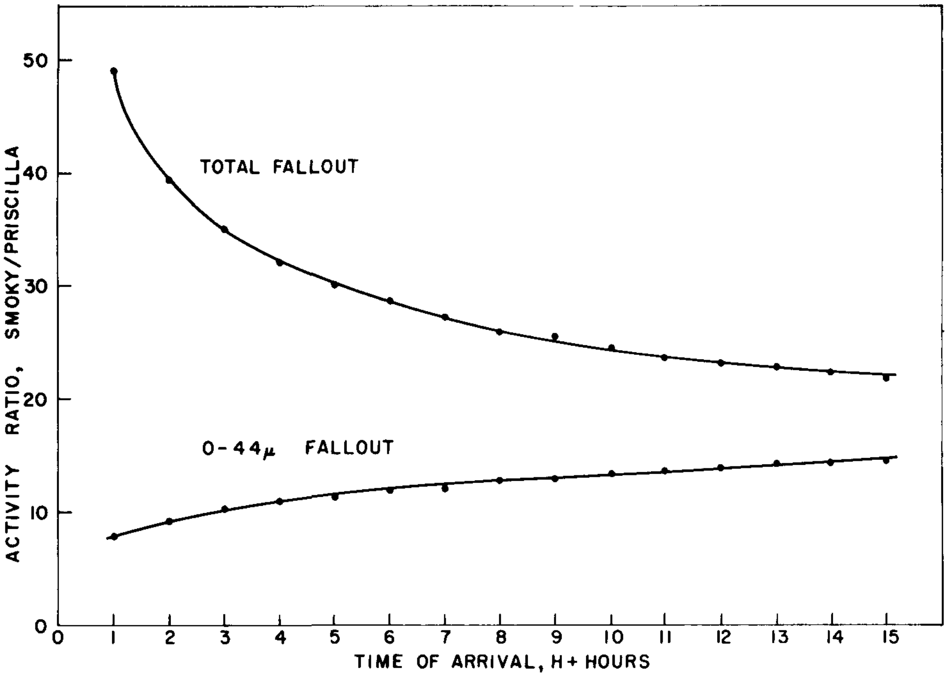


Figure 5.7 Smoky-to-Priscilla Activity Ratios Versus Various Fallout Times-of-Arrival.

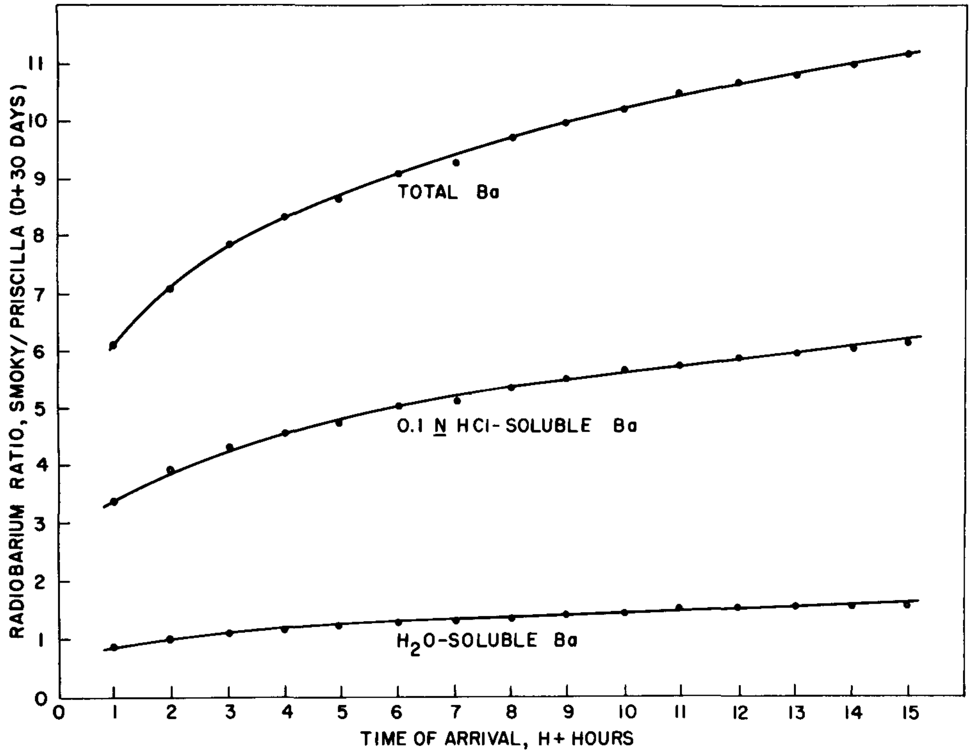


Figure 5.8 Calculated Smoky-to-Priscilla Total, Acid-Soluble, and Water-Soluble Less Than 44 Micron Fallout Ba^{140} Ratios at Various Times-of-Arrival.

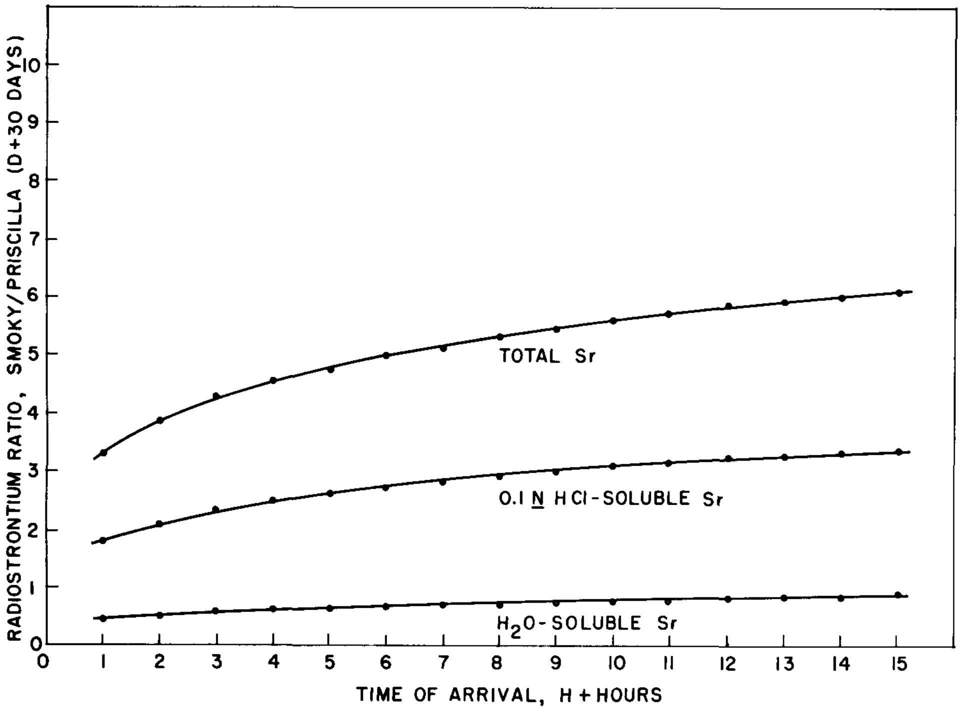


Figure 5.9 Calculated Smoky-to-Priscilla Total, Acid-Soluble, and Water-Soluble Less Than 44 Micron Fallout Sr^{89} Ratios at Various Times-of-Arrival.

exceed those from Shot Priscilla, and more water-soluble Sr^{89} occurs over the 15 hour fallout period due to Shot Priscilla than to Shot Smoky.

The above examples support the assumption that total fallout radioactivity levels may be poor indicators of potential biological accumulation of fission products derived from fallout debris depending upon the applicability of water and 0.1N HCl extractions as indices of biological availability. If such indices are applicable, low radiation levels of balloon shot fallout may result in equivalent or greater biological uptake than the higher levels of tower shot fallout.

5.4.2 Close-in Deposition of Sr^{89} and Sr^{90} by Plumbbob Shots

On the basis of data reported elsewhere in this report, the amounts of Sr^{89} and Sr^{90} deposited in close-in fallout (one mile from ground zero to the distance at which fallout arrived at H + 12 hours) in relation to those amounts available for deposition at greater distances may be estimated for several Plumbbob detonations.

The calculations for each shot were based on (1) total fallout levels from one mile from ground zero to H + 12 hour fallout time in terms of (mr/hr) (mi^2) at H + 12 hours; (2) mean μc/sq ft : mr/hr ratios at H + 12 hours (Chapter 2); (3) mean Sr^{89} percentages of total beta activity of different particle size fractions at D + 30 days (Figure 5.3) weighted according to the distribution of greater and less than 44 micron size fractions in tower shots and the Priscilla balloon shot (Chapter 3); (4) mean Sr^{90} percentages of total beta activity assuming no particle size fractionation (Table 5.5); (5) Sr^{89} and beta activity extrapolations from D + 30 days to H + 12 hours on the basis of 53 day half-life and the composite Plumbbob beta decay curve (Figure 4.11), respectively; (6) production of one gram or 2.77×10^4 curies of Sr^{89} per kt, and (7) production of 1.14 grams or 146 curies of Sr^{90} per kt (U^{235}) (References 1 and 2).

The relative amounts of Sr^{89} and Sr^{90} deposited within the limits of one mile from ground zero and H + 12 hour fallout time appear in Table 5.8. Tower mounted shots deposited maximums of two percent of the total Sr^{89} and seven percent of the total Sr^{90} theoretically assumed to be produced; balloon mounted shots deposited a maximum of 0.1 percent of the total Sr^{89} produced. Consequently, in excess of 90 percent of the $Sr^{89,90}$ produced by the tower and balloon mounted shots for which measurements were made was associated with fallout occurring at fallout times greater than H + 12 hours.

TABLE 5.8 Estimated Sr^{89} and Sr^{90} Deposition from one Mile from Ground Zero to Fallout Arrival Time of H + 12 Hours

Shot	Yield, kt	H + 12 hours Distance, Miles	Pct Deposited Sr^{89}	Pct Deposited Sr^{90}
Tower mounted Shots				
Fizeau	11	160	0.4	1.6
Galileo	11	83	0.8	2.8
Boltzmann	12	213	1.8	6.3
Shasta	17	150	2.1	7.2
Diablo	17	146	1.2	4.3
Whitney	19	87	1.6	5.7
Smoky	44	238	1.7	6.0
Balloon mounted Shots				
Wilson	10	92	0.04	--
Newton	12	200	0.004	--
Priscilla	37	260	0.13	--
Hood	74	365	0.008	--

5.5 SUMMARY

(1) Balloon mounted shot fallout was essentially non magnetic. In contrast, tower mounted shot particle sizes larger than 44 microns were 56 to 84 percent magnetic; particles less than 44 microns were of the order of 10 percent magnetic with the exception of Shot Smoky where the magnetic fraction was 46.3 percent.

(2) Successive one-hour exposures to 10 ml of water indicated that the total water-soluble radioactivities removed by four extractions of the Priscilla and Diablo fallout were 45 to 90 and 20 to 96 percent larger, respectively, than those removed by single extractions. Four successive extractions of Priscilla and Diablo fallout each with 10 ml of 0.1 N NCl produced total acid-soluble radioactivities which were 10 to 22 and 48 to 90 percent larger, respectively, than those obtained by single extractions.

Based on single extractions: (a) Tower mounted shot nonmagnetic fallout was 3 to 10 times more soluble in water and 1.3 to 3 times more soluble in 0.1 N HCl than magnetic fallout; (b) solubility of tower mounted shot fallout in water or acid increased with decreasing particle size, and the reverse was true of balloon mounted shot fallout; (c) the water solubility of tower mounted shot fallout was 2 percent of the total beta radioactivity or less and that of balloon mounted shot fallout was 14 percent for the predominant less than 44 micron particle size; (d) the 0.1 N HCl solubility of tower mounted shot fallout was 5 percent for sizes greater than 44 microns (except for 24 percent of Smoky fallout) and 14 to 36 percent for less than 44 micron particle size; the 0.1 N HCl solubility of balloon mounted shot fallout was 65 percent of the total beta radioactivity for less than 44 micron particle sizes.

(3) Radiochemical analysis of tower and balloon mounted shot fallout materials indicated that, as of D + 30 days, $Ru^{103,106}$ and Sr^{89} percentages of total beta radioactivity tended to increase with decreasing particle sizes, and Ce^{141}+ $Ce\text{-}Pr^{144}$ percentages tended to decrease. Fractionation trends with respect to particle size were less definitive for Ba^{140}, Y^{91}, Zr^{95} and Sr^{90}.

Priscilla radionuclide percentages were approximately 30 percent higher for Ba^{140}, 11 to 38 percent higher for Ce^{141}+$Ce\text{-}Pr^{144}$, 300 to 400 percent higher for $Ru^{103,106}$, 250 percent higher for Sr^{89}, 20 to 50 percent higher for Y^{91}, and 50 percent lower for Zr^{95} than mean tower mounted shot percentages of corresponding size fractions.

(4) Tower mounted shot fallout particles were predominantly opaque with small percentages of transparent or transluscent particles. Balloon fallout particles were transparent or transluscent. Opaque particles for Shot Diablo averaged 1.06 microcuries per particle at H + 12 hours for sizes from 2000 to 88 microns in diameter and 0.31 microcuries per particle for 44 to 88 micron particles. Transparent Diablo particles averaged 0.19 microcurie per particle. Opaque 250 to 44 micron Shasta particles averaged 0.49 microcurie per particle at H + 12 hours, and transparent particles averaged 0.17 microcurie per particle.

(5) A comparison of Shots Smoky and Priscilla, utilizing integrated levels of activity associated with less than 44 micron fallout, the percent of soluble activity, and percent of radionuclides, indicated that over the 1 to 15 hour fallout time period the amounts of water-soluble Ba^{140} and Sr^{89} deposited by the two shots were similar despite relatively large differences in the deposited activity of less than 44 micron fractions.

(6) Within the limits of one mile from ground zero and H + 12 hours fallout time, tower shots deposited maximums of two percent of the total Sr^{89} and seven percent of the total Sr^{90} produced; balloon shots deposited a maximum of 0.1 percent of the total Sr^{89} produced.

REFERENCES

1. Chief, AFSWP, Washington, D. C.; Letter to: Commander, Field Command, AFSWP, Albuquerque, New Mexico; AFSWP-978, Subject: "Evaluation of Radioactive Fallout", 15 September 1955; Secret Restricted data.

2. E. A. Martell; "The Chicago Sunshine Method; Absolute Assay of $Strontium^{90}$ in Biological Materials, Soils, Waters, and Air Filters"; May 1956; The Enrico Fermi Institute for Nuclear Studies, University of Chicago; Chicago, Illinois; Unclassified.

CHAPTER 6

THE BEHAVIOR OF FALLOUT IN THE ENVIRONMENT

A fifth and final phase in characterizing the fallout pattern involves a determination of the manner and extent to which the initial fallout is redistributed in the environment. Apart from radioactive decay, the principal variables which seem likely to affect changes in dose-rate levels and cause redistribution will include: wind, water, both as rain and surface runoff, thermal agitation, properties of specific soil types as they interact with radionuclides of particular physicochemical properties, and biotic cycling. These environmental factors have a bearing on the extent to which contamination and recontamination are to be anticipated. When these factors are measured, the data contribute to understanding the extent to which various environmental factors and time can modify biological availability of certain radionuclides.

6.1 PROCEDURE

6.1 1 Selection of Persistence Study Areas

The fallout patterns resulting from Shots Priscilla and Smoky were chosen for detailed comparison on the basis of similarity in yield and height of burst and difference in support of the devices. Sampling locations were selected on the basis of accessibility and their position within the patterns as delineated by Projects 37.2 and 37.2a. On D + 2 and D + 3 days after these two shots, sampling areas approximately four miles in length (along the midline) and one mile in width (across the midline) were delineated by radiation intensity readings taken at 100-yard intervals along both axes by Project 37.1. A microstudy area (persistence station) was selected on the midline within each delineated area. Four such stations were established along the midline between 68 and 197 miles from ground zero in the Priscilla pattern. Two stations, 99 and 136 miles from ground zero, were selected in the Smoky pattern. The stations were established by 1600 hours on D + 3 days and maintained continuously to D + 21 days.

Environmental variables that might differ between the two studies such as terrain, climate, and biota were greatly reduced by the Smoky pattern tending to overlay the Priscilla fallout within the segments of the fallout patterns compared The degree of contamination at comparable locations between the two shots was five to ten times greater for Smoky than for Priscilla, permitting easy identification of the sources of contamination.

Persistence stations were all designated by Roman numerals, i. e., I, III, IV, and V for Shot Priscilla and VI and VII for Shot Smoky. The extent and nature of fallout contamination (as determined by Projects 37.2 and 37 2a) at persistence stations are summarized in Table 6.1.

3

TABLE 6.1 Extent and Nature of Fallout Contamination at Persistence Stations

	Shot Priscilla (24 June, 0630 hrs)				Shot Smoky (31 August, 0530 hrs)	
Station No.	I[a]	III	IV	V	VI[a]	VII
Miles from ground zero	68	129	155	197	99	136
Miles from midline	0	1.0 N	2.0 N	4.0 N	0	0.2S
Fallout time-of-arrival, H + hrs	4.5	7.1	9.5	9.5	4.5	4.8
Dose rate, mr/hr at H + 12 hrs	22.5	4.7	≈ 1.0	≈ 2.0	55	27
Unit area activity, μc/sq ft at H + 12 hrs	32	9.2	≤ 8.2	~ 6.3	~680	≈310
Percent $<44\mu$ fraction deposited	80	85	82	78	38	?

[a] See Figure 2.3 (Priscilla) and Figure 2.7a (Smoky) for locations within the patterns.

6.1.2 Documentation of Persistence Study Areas

Each persistence study area was documented radiologically by daily beta and gamma survey meter measurements, a recording gamma radiation monitor (PRAM), and two types of film packs. Each area was documented climatologically by a recording hygrothermograph, a rain gauge, and two recording anemometers (one at 0.5 foot and the other at 3 feet above the soil surface). Soil and air levels of fallout radioactivity were documented by serially collected soil, air, and granular collector samples. Native animal and plant radio-activity levels were documented by serial sampling of rodents, jackrabbits, and several plant species. The procedures employed are described in detail in Appendix A.

A typical persistence study area is diagramed in Figure 6.1.

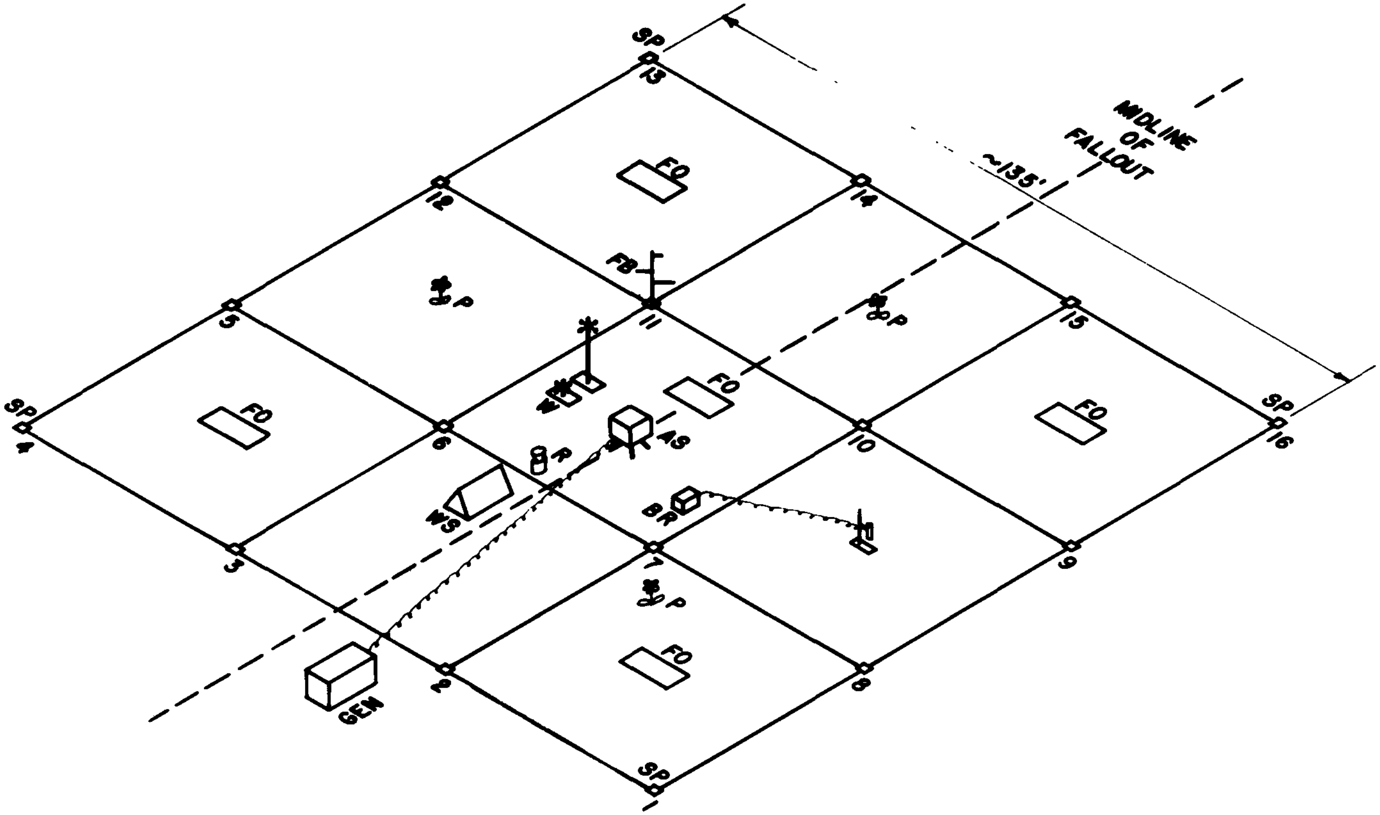
6.2 RESULTS

6.2.1 Microclimatology

Continuous measurements of air temperature and relative humidity indicated diurnal cycles at all stations with maximum temperature (~15 percent) occurring between 1200 and 1300 hours (PDT). Minimum air temperature (~32 °F) and maximum relative humidity (50 to 60 percent) occurred between 0300 and 0600 hours (PDT)

Rain when present (one day during both Priscilla and Smoky studies) occurred at all stations at similar times and intensities.

Minor variations in lateral wind speed existed between the various persistence stations during both studies. The periods of wind activity were similar for all stations maintained during the same time periods both on an hourly and daily basis (Figures 6.2 and 6.3). Maximum wind speeds (~12 to 15 mph) occurred at ~1300 hours (PDT).



AS	AIR SAMPLER
BR	BACKGROUND RECORDER
FB	FILM BADGE DOSIMETERS
FO	GRANULAR FALLOUT COLLECTOR
GEN	GENERATOR
P	PLANT LABELED FOR SEQUENTIAL SAMPLING
R	RAIN COLLECTOR
SP	SOIL PROFILE
W	WIND SPEED RECORDER
WS	WEATHER SHELTER
1-16	MONITORING STAKES AND SURFACE SOIL SAMPLING LOCATIONS

FIGURE 6.1 Persistence Station Layout of Instrumentation and Sample Locations.

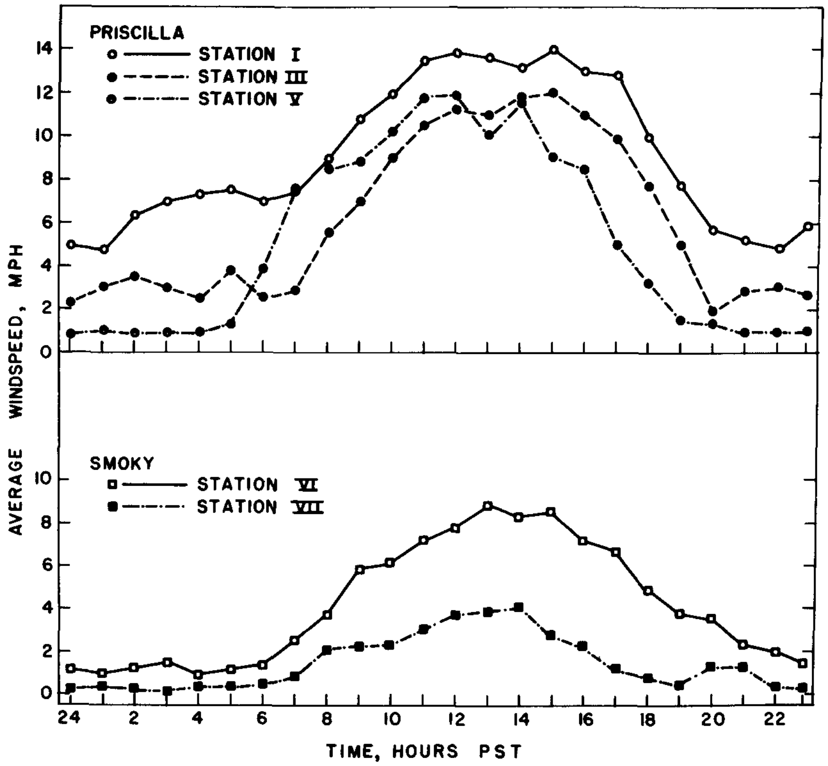


FIGURE 6.2 Average Hourly Windspeeds at Shots Priscilla and Smoky Persistence Stations. Anemometer 3 Feet Above Soil Surface.

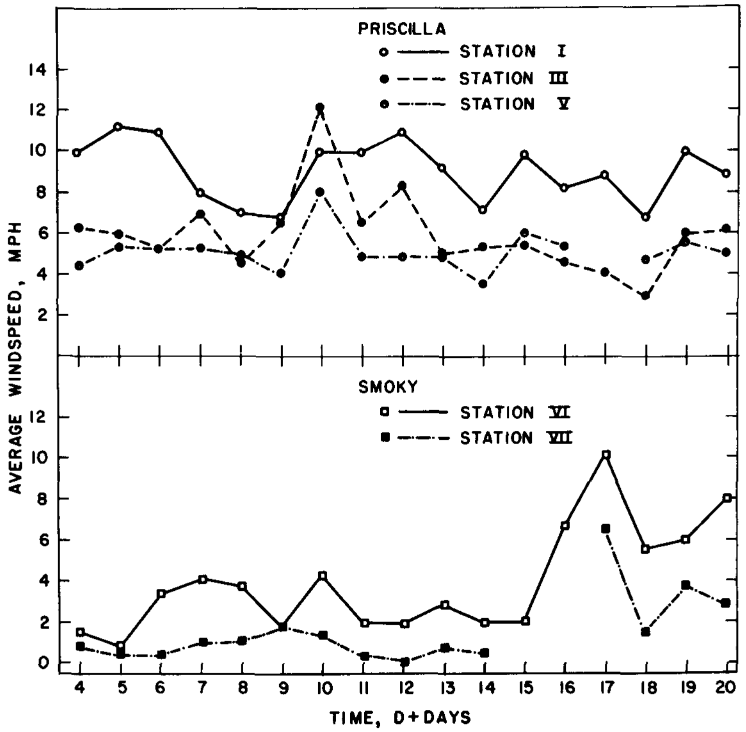


FIGURE 6.3 Average Daily Windspeeds at Shots Priscilla and Smoky Persistence Stations. Anemometer 3 Feet Above Soil Surface.

There was a marked reduction in wind speeds measured at 6 inches above the soil surface as compared with speeds at 36 inches above the soil surface at all but one station. Wind speeds at the 6 inch height were less than 3 mph which was below the sensitivity of the anemometers used. At the sparsely vegetated and exposed Station VI, the wind speeds were similar at both the 6 inch and 36 inch heights.

Generally speaking, over an 18 day study period, all instrumented stations tended to show the same time relationship between daily air temperature, relative humidity, and lateral air movement: high temperature, low relative humidity, and maximum air movement at approximately 1300 hours and, conversely, low temperature, high relative humidity, and minimum lateral air movement at approximately 0300 hours.

6.2.2 Persistence of the Radiation Field

Radiation intensity was measured daily between D + 3 and D + 20 days at each of the 16 stakes indicated in Figure 6.1. The 16 values were averaged and used to plot the decay of radioactive material in the field. Readings were taken each day in a uniform manner both with the window open and with the window closed at heights of 1 inch and 36 inches above the soil surface. GM-type survey instruments were used for both studies. Because of a shortage of survey meters of the type used by Project 37.2a, it was necessary to undertake the post-Priscilla studies with a variety of GM survey instruments including the Thyac, Precision 107, and Nuclear 2610A. Readings were further complicated by the low intensity of contamination. During the post-Priscilla survey most readings were less than 1 mr/hr intensity which made objective reading of the instruments difficult. The instruments were not calibrated on the x1 scale. Instrument background as determined well outside the fallout pattern was subtracted from the observed readings. Despite these handicaps, the agreement between radioactive decay observed in the field and decay of comparable isolated fallout samples in the laboratory was good and lends credence to the monitoring data presented in Tables 6.2 (Priscilla) and 6.3 (Smoky).

It will be noted that two values, expressed in mr/hr, are presented in the tables: the observed reading and a T-1B equivalent value consistent with the recommendations of the Test Director's Organization (Chapter 2).

Generally the GM survey meter readings with the window closed were similar whether taken at 1 inch or 36 inches above the soil, with the 1 inch readings tending to give slightly higher response. Meter readings taken with the window open were approximately twice as high when taken at 1 inch as when taken 36 inches above the soil surface.

No effect of shielding by the body of the operator could be found for readings taken at 3 feet above the ground surface with the window either open or closed.

TABLE 6.2 Field Measurements of Radiation Decay, Shot Priscilla

Condition of Measurement GM Probe Position Height above Soil	Date H+day	Time H+hrs	Sta. I[a]		Sta. III		Sta. IV		Sta V	
			Obs	Norm	Obs	Norm	Obs	Norm	Obs	Norm
			mr/hr less instrument background[b]							
36 inches, window closed	3	76	0.64	0.90	0.26	0.36	0.18	0.25	0.05	0.07
	5	124	0.37	0.52	0.12	0.17	0.04	0.06	0.01	0.01
	9	220	0.17	0.24	0.05	0.07	0.03	0.04	nil	--
	13	316	0.10	0.14	0.03	0.04	0.02	0.03	nil	--
	20	484	0.04	0.06	0.02	0.03	0.01	0.01	nil	--
Decay Constant[c]			-1.47		-1.41		-1.40		--	
36 inches, window open	3	76	2.29	3.20	0.94	1.32	0.31	0.43	0.27	0.38
	5	124	1.41	1.97	0.23	0.32	0.13	0.18	0.07	0.10
	9	220	0.61	0.85	0.14	0.20	0.07	0.10	0.03	0.04
	13	316	0.35	0.49	0.09	0.13	0.05	0.07	0.02	0.03
	20	484	0.12	0.17	0.05	0.07	0.02	0.03	0.03	0.04
Decay Constant			-1.56		-1.48		-1.38		-1.25	
1 inch, window closed	3	76	0.77	1.08	0.33	0.46	0.18	0.25	0.05	0.07
	5	124	0.43	0.60	0.16	0.22	0.05	0.07	0.02	0.03
	9	220	0.19	0.27	0.06	0.08	0.04	0.06	0.01	0.01
	13	316	0.12	0.17	0.04	0.06	0.03	0.04	0.01	0.01
	20	484	0.05	0.07	0.03	0.04	0.02	0.03	0.01	0.01
Decay Constant			-1.40		-1.34		-1.07		--	
1 inch, window open	3	76	6.40	8.96	1.79	2.51	0.47	0.66	0.52	0.73
	5	124	3.28	4.59	0.58	0.81	0.24	0.34	0.23	0.32
	9	220	1.54	2.16	0.53	0.74	0.18	0.25	0.08	0.11
	13	316	0.90	1.26	0.40	0.56	0.11	0.15	0.06	0.08
	20	484	0.33	0.46	0.11	0.15	0.07	0.10	0.07	0.10
Decay Constant			-1.56		-0.53		-0.98		--	

[a] Observed values (Obs) normalized to T-1B survey meter, correction factor = 1.4.

[b] Instruments not calibrated on x1 scale, Avg. of 16 readings within 14,400 sq. ft.

[c] Exponent in expression $A = A_0 T^{-k}$.

TABLE 6.3 Field Measurements of Radiation Decay, Shot Smoky

Conditions of Measurement GM Probe Position Height above Soil	Date H+day	Time H+hrs	Sta. VI Obs	 Norm[a]	Sta. VII Obs	 Norm
			mr/hr less instrument background[b]			
36 inches, window closed	1	27	19.2	36.5	-	-
	3	77	5.0	9.5	1.53	2.91
	5	125	3.25	6.18	0.94	1.79
	9	221	2.57[d]	4.88	0.58	1.10
	13	317	1.05	2.00	0.37	0.70
	20	485	0.65	1.24	0.25	0.48
Decay Constant[c]			-1.16		-1.04	
36 inches, window open	3	77	21.3	40.5	7.73	14.7
	5	125	11.0	20.9	5.40	10.3
	9	221	5.84	11.1	1.65	3.14
	13	317	3.90	7.41	1.20	2.28
	20	485	1.63[d]	3.10	0.79	1.50
Decay Constant			-1.19		-1.23	
1 inch, window closed	3	77	5.98	11.4	1.63	3.10
	5	125	3.93	7.45	1.02	1.94
	9	221	2.80[d]	5.32	0.66	1.25
	13	317	1.27	2.41	0.41	0.78
	20	485	0.78	1.48	0.26	0.49
Decay Constant			-1.13		-0.99	
1 inch, window open	3	77	>20	--	9.78	18.6
	5	125	>20	--	5.58	10.6
	9	221	17.6	33.4	2.71	5.15
	13	317	11.8	22.4	1.41	2.68
	20	485	5.3	10.1	0.86	1.63
Decay Constant			-1.58		--	

[a] Observed values (Obs) normalized to T-1B survey meter; correction factor = 1.9.

[b] Avg. of 16 readings within 14,400 sq ft.

[c] Exponent in expression $A = A_0 T^{-k}$.

[d] Not included in slope determinations.

Residual fallout intensities were below the sensitivities of the recording gamma radiation monitor. The instrument was nevertheless maintained to document possible contamination from subsequent detonations.

6.2.3 Film Pack Dosimeters

Two kinds of film badge dosimeters were exposed serially to document dose rate in the field. The great variability of accumulated dose measured by different badges exposed for similar lengths of time under similar circumstances made it desirable to combine the badges into four comparable groups representing each condition of exposure with each group representing the total accumulated dose between H + 80 and H + 480 hours. Since the film badges were read to an accuracy of 5 percent, the agreement between replications in the field is the limiting factor regarding the reliability of the data (Tables 6.4 and 6.5).

In most cases higher beta and gamma doses were measured 1 inch above the ground than at either 18 inches or 36 inches above ground. Badges placed under or over bushes accumulated similar but lower doses than comparable badges placed in the open. Despite this, the beta-to-gamma ratio estimated from the film badge data tends to be higher for badges exposed at the base of plants than in other positions.

An estimation of the beta and gamma ray attenuation in air was derived from the film badge data by averaging all badges exposed during the post-Priscilla and -Smoky studies (Table 6.6).

6.2.4 Persistence of Fallout Contamination in Surface Soil

Soil samples were collected serially from all persistence stations maintained following Priscilla and Smoky detonations. The samples were processed as described in Appendix A.

The level of contamination resulting from Priscilla fallout was below the sensitivity of the soil processing procedures (Appendix A). The surface soil contamination resulting from Smoky fallout is summarized in Table 6.7. Between D + 3 and D + 20 days, no significant change in the concentration of fallout debris in the surface soil could be demonstrated. Ten months following fallout contamination from Smoky shot, Stations VI and VII were resampled. The predicted level of contamination (interpolated from D day data), the observed level of contamination between D + 3 and D + 20 days, and the observed level of contamination on D + 300 days are summarized in Table 6 8. No significant change in concentration of fallout debris in surface soil between D day and D + 300 days could be demonstrated. The possible significance of the increase in the coefficient of variation between D + 3, D + 20, and D + 300 days is discussed in Section 6.3.1.

Soil profiles to a depth of 4 inches were sampled at Stations VI and VII on D + 3, D + 20, and D + 300 days. While beta activity was detected below the surface inch of

TABLE 6.4 Radiation Dose Measured by Film Badge Dosimeters, Shot Priscilla

Position, Inches above Soil Surface	Gamma, rad[a]		Beta, rad Standard		Beta, rad Thin Window		Beta-to-Gamma Ratio Standard	Beta-to-Gamma Ratio Thin Window
Station I	Mean	S.D.	Mean	S.D.	Mean	S.D.		
1	245	71	190	62	412	30	0.78	1.68
1, under bush	178	66	323	100	424	42	1.81	2.38
18	390	98	273	257	108	71	0.70	0.28
18, over bush	258	78	96	97	94	56	0.37	0.36
36	254	47	178	88	100	27	0.70	0.39
Station III								
1	183	182	48	8.9	140	98	0.25	0.77
1, under bush	152	35	98	68	168	24	0.64	1.11
18	110	b	65	44	80	36	0.59	0.72
18, over bush	120	b	10	b	60	b	0.08	0.50
36	90	89	83	116	70	53	0.92	0.78
Station IV								
1	153	44	40	15	202	4.5	0.26	1.32
1, under bush	43	5.9	53	30	100	12	1.23	2.31
18	66	12	32	15	65	b	0.47	0.97
18, over bush	88	67	7.5	4.5	42	18	0.08	0.48
36	55	29	2.5	4.9	36	27	0.04	0.66
Station V								
1	35	8.9	18	22	60	18	0.51	1.71
1, under bush	20	--	13	4.5	30	b	0.68	1.50
18	20	15	12	15	10	18	0.60	0.50
18, over bush	28	32	10	12	10	12	0.36	0.36
36	60	53	2.5	4.5	--		0.04	--

[a] Dose accumulated during 400 hour exposure beginning at H + 80 hours. Beta and gamma dose measured both by standard and experimental "thin window" film pack dosimeters. Standard deviation (S.D.) determined from 4 replicate groups of serially exposed film badges.

[b] Only one group represented

TABLE 6.5 Radiation Dose Measured by Film Badge Dosimeters, Shot Smoky

Position, Inches above Soil Surface	Gamma, rad[a]		Beta, rad Standard		Beta, rad Thin Window		Beta-to-Gamma Ratio Standard	Beta-to-Gamma Ratio Thin Window
Station VI	Mean	S.D.	Mean	S.D.	Mean	S.D.		
1	1250	147	3368	1720	5396	1646	2.69	4.32
1, under bush	1263	191	4165	708	7135	1681	3.30	5.35
18	990	159	2680	1100	7853	4013	2.71	7.93
18, over bush	905	88	1670	417	2390	549	1.85	2.64
36	881	167	2329	358	7080	5341	2.64	8.04
Station VII								
1	488	152	2505	238	4095	779	5.13	8.39
1, under bush	339	4.9	1870	635	3141	311	5.52	9.27
18	408	66	1339	191	1384	147	3.28	3.39
18, over bush	338	20	496	39	544	74	1.47	1.61
36	374	25	805	37	818	49	2.15	2.19

---

[a] Dose accumulated during 400 hours exposure beginning at H + 80 hours. Standard deviation (S.D.) determined from four replicate groups of serially exposed film badges. Beta and gamma dose measured both by standard and experimental "thin window" film pack dosimeters.

TABLE 6.6 Measured Attenuation of Beta and Gamma Radiation from Fallout

Distance above Soil Surface, in.	Pct Attenuation[a] Gamma	Beta		Beta-to-Gamma Ratio	
		Standard	Thin Window	Standard	Thin Window
1	0	0	0	0.26	0.44
18	15.7	28.6	7.9	0.22	0.48
36	27.2	44.2	21.4	0.20	0.47

[a] Derived from means of all badges exposed between H + 80 and H + 400 hours during post-Priscilla (Table 6.4) and post-Smoky (Table 6.5) studies.

TABLE 6.7 Persistence of Beta Activity in the Soil Surface, Shot Smoky

Time of Sampling D + days	Station VI	Station VIII
	μc/sq ft, H + 12 hours	
3	1092 ± 228	361 ± 60
5	1040 ± 196	266 ± 25
9	862 ± 123	308 ± 28
13	969 ± 36	324 ± 75
20	866 ± 110	373 ± 69
Mean (D + 3 to D + 20 days)	966 ± 91	326 ± 46

TABLE 6.8 Predicted and Observed Contamination Persistence in Soil Surface

	Predicted from D day Measurements	Observed D + 3 to D + 20 days	D + 300 days
	μc/sq ft, H + 12 hours		
Station VI	680[a]	966 ± 91	830 ± 280
Coefficient of Variation		9.4%	33.5%
Station VII	310[b]	326 ± 46	468 ± 205
Coefficient of Variation		14%	43.8%

[a] from granular collector data

[b] from surface soil data

soil, the intensity did not permit a quantitative expression of activity because of the limitations in the soil sampling procedures. In view of the apparent immobility of contamination in the surface soil, the data were interpreted to mean that downward migration of total beta activity resulting from contamination of surface soil by Smoky fallout was negligible or had not occurred.

Lack of downward migration of total beta activity cannot be accounted for entirely in terms of low rainfall since the winter season had occurred between D + 20 and D + 300 days. The amount of precipitation received at St. George, Utah (10.8 miles south of Station VII) between September 1957 and July 1958 was 12.22 inches, and the precipitation recorded at Veyo, Utah (7 miles north of Station VII) was 21.13 inches (Reference 1). Station VII, therefore, is estimated to have received between 12 and 20 inches of precipitation between D + 20 and D + 300 days. Station VI was in a remote area for which reliable rainfall figures are not available.

6.2.5 Redistribution of Surface deposited Fallout

The maximum daily movement of residual fallout was determined to be 0.975 μc/sq ft (H + 12 hours) on D + 16 days following Priscilla fallout and 4.71 μc/sq ft (H + 12 hours) on D + 17 days following Smoky fallout. All data presented regarding redistribution of fallout material have been corrected to a common time of H + 12 hours to permit assessment of the fate of the fallout material in the environment apart from radioactive decay. The reported levels should not be confused with the radiation intensity at the time of collection which was much lower (Table 6.9).

During both studies there was a definite downward trend with time regarding the amount of residual fallout being redistributed (Figure 6.4). An exception occurred during the Smoky study in which the maximum redistribution was observed at D + 17 days. The high tray values measured following Smoky correlate well with the periods of maximum lateral air movement (Figure 6.3). However, the correlation between redistribution and air movement is not apparent for data collected following Priscilla.

Fallout trays maintained during rains indicate a period of relatively high redistribution. However, data from the entire 18 day study period showed that redistribution had not been effective in changing the mean concentration of residual fallout. Because of the special handling and processing required for wet samples, these data are probably not comparable to data from dry samples, and the values have not been included in determination of the means.

During the post-Priscilla study, the 44-88 micron fallout particles contributed an average of 9.7 percent of the total redistributed radioactivity as compared to 21.0 percent during the Smoky study. Particles less than 44 microns in diameter contributed an average of 85.8 percent of the redistributed fallout following Priscilla as compared to 68.3 percent following Smoky (Figure 6.5).

TABLE 6.9 Daily Redistribution of Fallout Material within the Priscilla and Smoky Fallout Patterns.

Mean values derived from 5 replication (24 hour exposures) of granular collectors between D + 3 to D + 20 days. Beta activities corrected to H + 12 hours.

	Shot Priscilla								Shot Smoky			
	Station I		Station III		Station IV		Station V		Station VI		Station VII	
Time	Mean[a]	S.D.[b]	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
D + Days	μc/sq ft		μc/sq ft		μc/sq ft		μc/sq ft		μc/sq ft		μc/sq ft	
3	0.064	0.015	0.060	0.010	0.015	0.0025	0.031	0.031	3.64	1.35	0.412	0.094
4	0.503	0.081	0.216	0.059	0.098	0.033	0.058	0.016	3.22	0.91	0.692	0.313
5	0.161	0.090	0.085	0.020	0.050	0.012	0.053	0.010	1.71	0.45	0.523	0.112
6	0.231	0.112	0.090	0.023	0.068	0.007	0.033	0.015	2.28	0.69	0.380	0.056
7	0.116	0.021	0.284	0.049	0.112	0.032	0.110	0.088	1.55	0.69	0.680	0.351
8	0.149	0.054	0.106	0.064	0.041	0.011	0.144	0.072	2.26	0.78	1.08	0.310
9	0.171	0.068	0.337	0.080	0.110	0.019	0.055	0.017	1.52	0.52	0.314	0.039
10	0.136	0.042	0.170	0.075	0.127	0.049	0.036	0.005	1.65	0.61	0.459	0.169
11	0.113	0.040	0.197	0.029	0.169	0.059	0.092	0.009	1.23	0.40	0.198	0.077
12	0.141	0.032	0.109	0.023	0.145	0.021	0.230	0.069	0.094	0.13	0.199	0.034
13	0.063	0.023	0.039	0.011	0.050	0.025	0.038	0.022	0.483	0.13	0.173	0.034
14	0.035	0.005	0.070	0.040	0.038	0.005	0.025	0.007	1.06	0.61	0.282	0.032
15	--	--	--	--	0.172	0.032	0.545	0.352	0.773	0.27	0.184	0.038
16	0.084	0.017	0.138	0.024	0.132	0.010	0.975	--	1.855	0.66	0.565	0.086
17	0.096	0.025	--	--	0.429	0.088	0.188	0.043	4.71	0.79	1.076	0.114
18	0.060	0.009	0.038	0.016	0.080	0.032	0.032	0.009	0.358	0.11	0.213	0.076
19	0.108	0.008	0.045	0.017	0.074	0.060	0.042	0.005	0.546	0.23	0.384	0.167
20	0.044	0.020	0.046	0.024	0.018	0.004	0.025	0.013	0.538	0.10	0.226	0.058

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[a] Total collecting area exposed at each station: 47.3 sq ft/day

[b] Standard Deviation

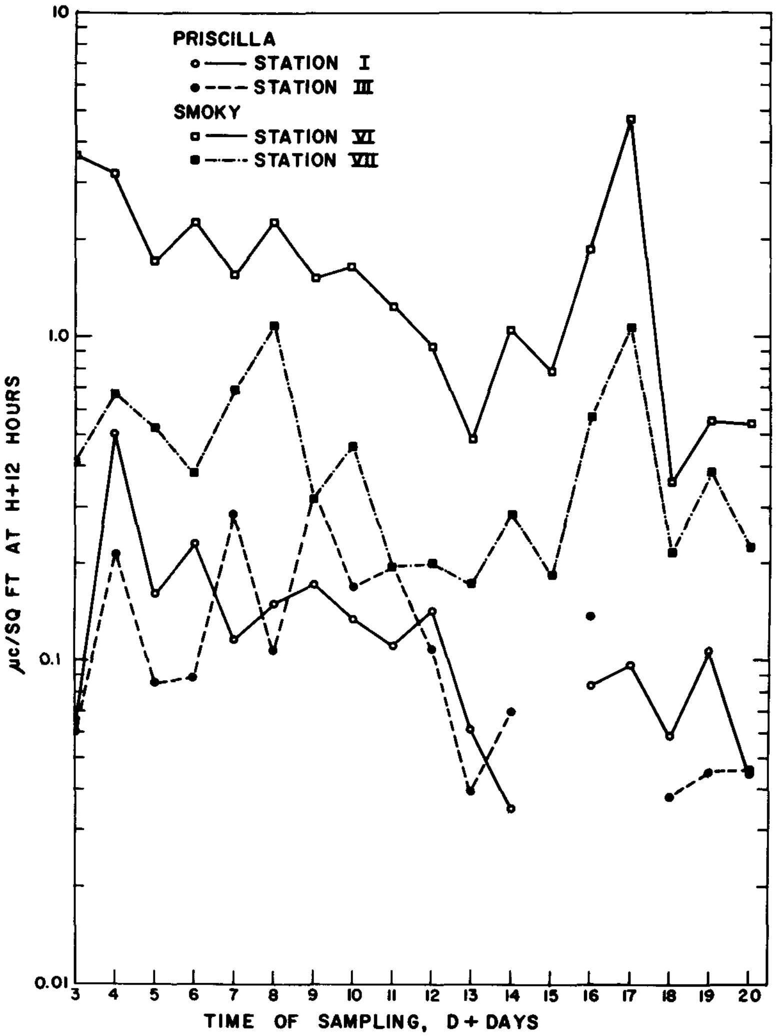

FIGURE 6.4 Daily Redistribution of Fallout Material in Selected Areas Within the Priscilla and Smoky Fallout Patterns from D +3 to D + 20 days.

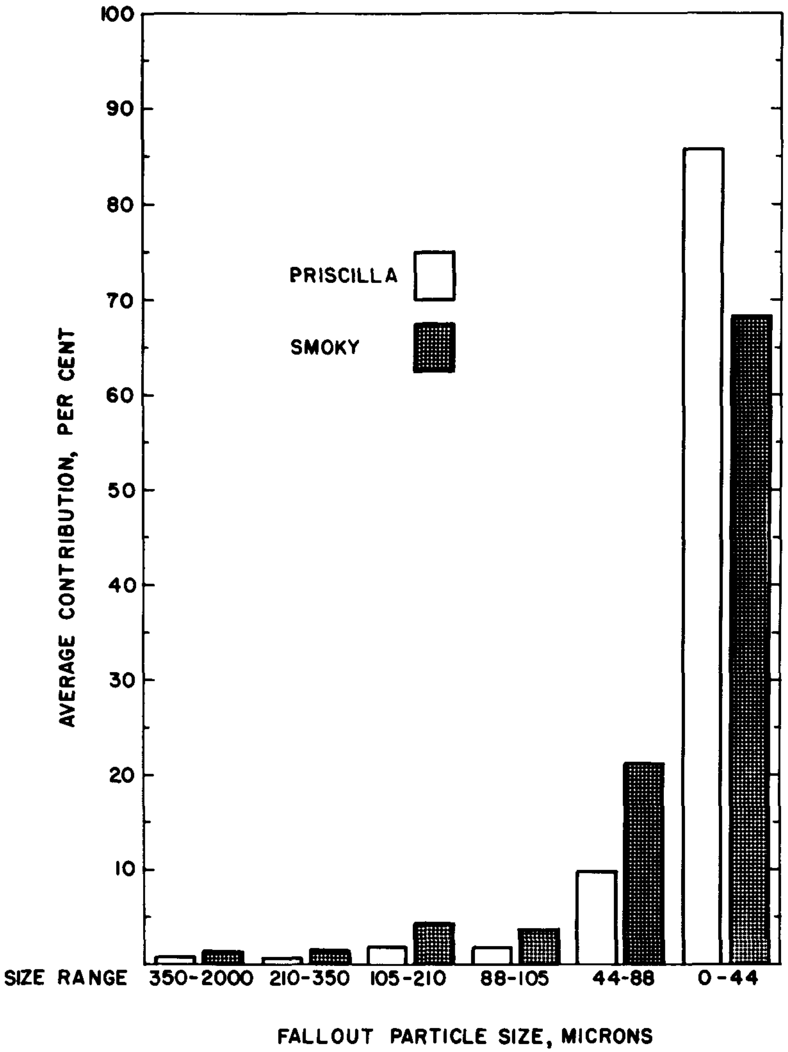

FIGURE 6.5 Relative Distribution of Selected Fallout Particle Size Fractions from Radioactive Debris Redistributed Between D + 3 and D + 20 Following Shots Priscilla and Smoky

6.2.6 Aerosol Concentration

Four stations maintained following Priscilla had 6-hour mean aerosol concentrations ranging as follows: Station I: 27.8 to 51.6 pc/ft^3; Station III: 41.0 to 57.7 pc/ft^3; Station IV: 26.5 to 45.7 pc/ft^3; Station V: 56.9 to 74.6 pc/ft^3. All values are corrected to the common time of H + 12 hours (Figure 6.6, Table 6.10.).

Because of extreme terrain features and possible discrepancies in station location with regard to the midline of fallout, Station IV is not directly comparable with the other areas. Omitting Station IV, there is an apparent increase in chronic air concentration with increasing distance from ground zero.

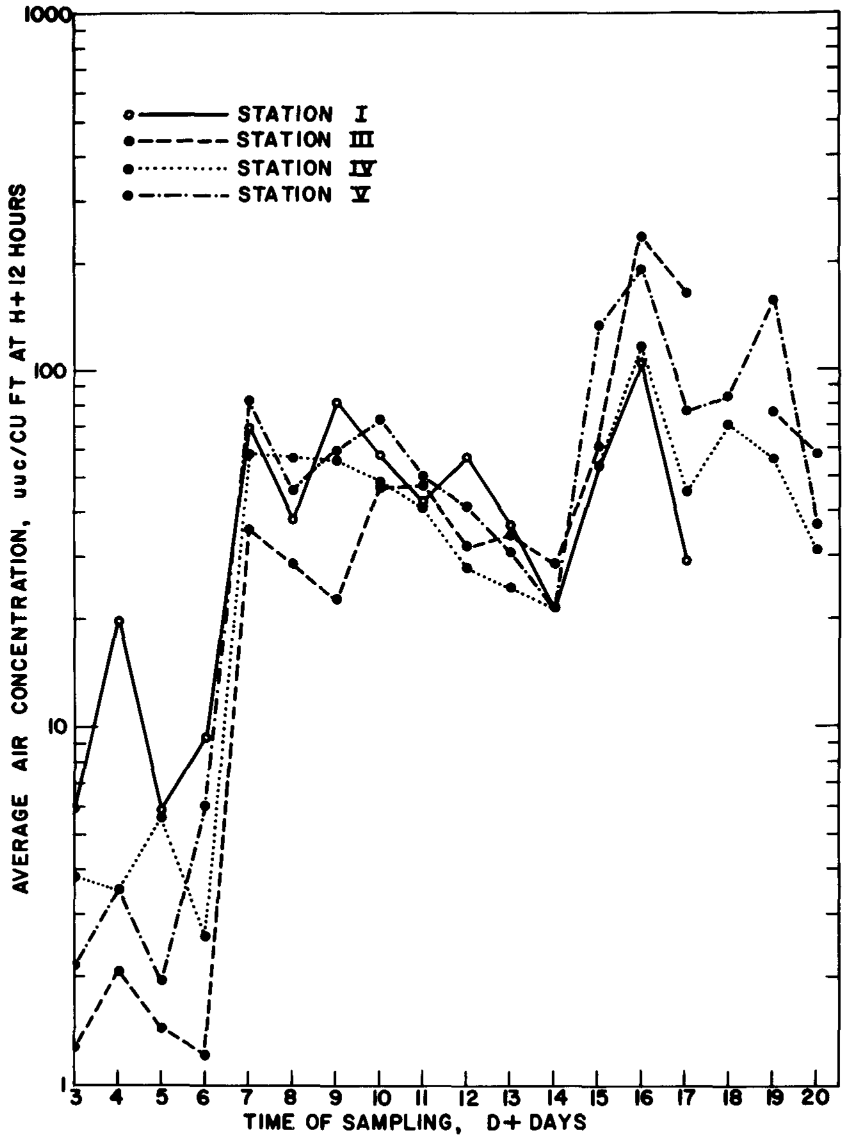

FIGURE 6.6 Average Radioactive Aerosol Concentrations at Priscilla Persistence Stations from D + 3 to D + 20 days.

TABLE 6.10 Persistence of Airborne Radioactivity in the Priscilla Fallout Pattern

Fission Product Concentration in Air, pc/ft^3 at H + 12 hrs.

Time D + Days	Station I Daily Sampling Period, hr 0400 to 1000	1000 to 1600	1600 to 2200	2200 to 0400	Daily Average	Station III Daily Sampling Period, hr 0400 to 1000	1000 to 1600	1600 to 2200	2200 to 0400	Daily Average
3	--	--	12.6[a]	5.99	5.99	--	0.35	0.35	2.23	1.29
4	5.63	49.1	21.9	2.74	19.8	0.32	2.67	5.34	Bkg	2.08
5	2.66	12.0	3.90	4.92	5.87	Bkg	2.91	1.91	0.97	1.44
6	4.36	9.93	11.0	12.5	9.44	1.00	2.14	1.72	Bkg	1.21
7	12.5	62.3	135	82.4[a]	69.9	5.40	42.6	52.7	40.2	35.2
8	--	11.9	61.6	38.1	37.2	31.0	24.2	29.9	28.2	28.3
9	31.5[a]	41.5	70.3[a]	122	81.8	13.4	19.7	17.0	39.0	22.3
10	65.6	53.5	60.8	50.3	57.6	8.92	47.1	70.2	58.3	46.1
11	30.2	--	40.2[a]	54.4	42.3	31.2	53.0	58.0	47.9	47.5
12	40.1	62.5	64.8	59.6	56.8	42.1[a]	27.4	31.4	36.4	31.7
13	48.8	29.1	26.3	40.7	36.2	23.4[a]	34.1	34.3	33.9	34.1
14	22.1	23.7	19.0	20.5	21.3	25.8	29.3	28.1	29.5	28.2
15	23.5	29.4	47.0	114	53.5	31.4	24.0	37.4	159	63.0
16	48.5	126	116	130	105	340	295	164	147	237
17	29.5	--	--	--	29.5	165	--	--	--	165
18	--	--	--	--	--	--	--	--	--	--
19	--	--	--	--	--	--	65.0	86.6	76.0	75.9
20	--	--	--	--	--	97.5	42.6	38.9	52.5	57.9
Average	27.8	42.5	51.6	50.4	43.0	57.7	54.2	41.0	44.0	49.2
	Station IV					Station V				
3	--	--	3.96	3.71	3.84	--	--	2.63	1.70	2.16
4	2.12	4.82	3.56	3.49	3.50	1.55	3.29	6.79	2.46	3.56
5	2.72	17.2	1.08	1.45	5.61	0.90	0.86	5.20	0.84	1.95
6	1.55[a]	4.44	2.39	0.95	2.59	2.47	19.7	1.37	0.65	6.04
7	3.97	40.4	104	83.5	58.0	22.5	59.3	137	113	83.0
8	69.8	63.0	45.2	46.9	56.2	1.81	53.6	65.5	60.0	45.2
9	39.1	36.8	58.0	87.6	55.4	54.3	70.9	44.3	69.9	59.9
10	41.5	45.7	54.6	51.3	48.3	104	65.5	59.2	61.0	72.4
11	38.9	43.8	42.8	41.0	41.6	52.1	46.9	55.6	45.2	50.0
12	32.9	25.6	25.0	26.9	27.6	38.8	39.5	47.1	37.4	40.7
13	22.7	20.6	25.3	28.4	24.3	29.2	26.6	27.1	39.1	30.5
14	24.7	22.2	20.2	20.2	21.8	28.1	18.8	20.9	18.4	21.6
15	24.2	19.0	19.4	150	53.2	14.1	13.4	77.0	419	131
16	31.6	174	151	106	116	252	229	116	167	191
17	76.8[a]	52.7	45.9	33.8	33.1	119	53.3	81.9	49.8	76.0
18	28.1	49.3	131	1.31[a]	69.5	38.0	65.3	88.4	137	82.2
19	8.6	109	45.3	56.3	54.8	184	174	180	93	158
20	44.5	27.7	30.9	34.7	31.1	59	27	33	27	36.5
Average	26.5	44.5	45.0	45.7	40.4	58.9	56.9	58.3	74.6	62.2

[a] Short exposure value not included in average.

Two stations maintained following Smoky yielded means ranging from 40.4 at Station VI to 52.0 pc/ft^3 at Station VII (Figure 6.7, Table 6.11).

The levels of aerosol concentration were similar during both the Priscilla and Smoky studies and do not reflect significant differences in the conditions of detonation. Stations III and VII are roughly comparable in location (Table 6.1). However, the degree of initial fallout contamination was quite different with H + 12 hour values of 4.7 mr/hr at Station III as compared to 27 mr/hr at Station VII. The measured levels of aerosol concentration, therefore, were similar despite differences of a factor of five in the levels of initial contamination.

The observed aerosol concentration following both Priscilla and Smoky did not appear to correlate with average daily lateral air movement (Figure 6.3). However, the diurnal peaks in aerosol concentration consistently coincided with periods of daily maximum temperature, low humidity, and maximum air movement, and, conversely, minimums in aerosol concentration consistently coincided with periods of daily minimum temperature, high humidity, and minimum air movement.

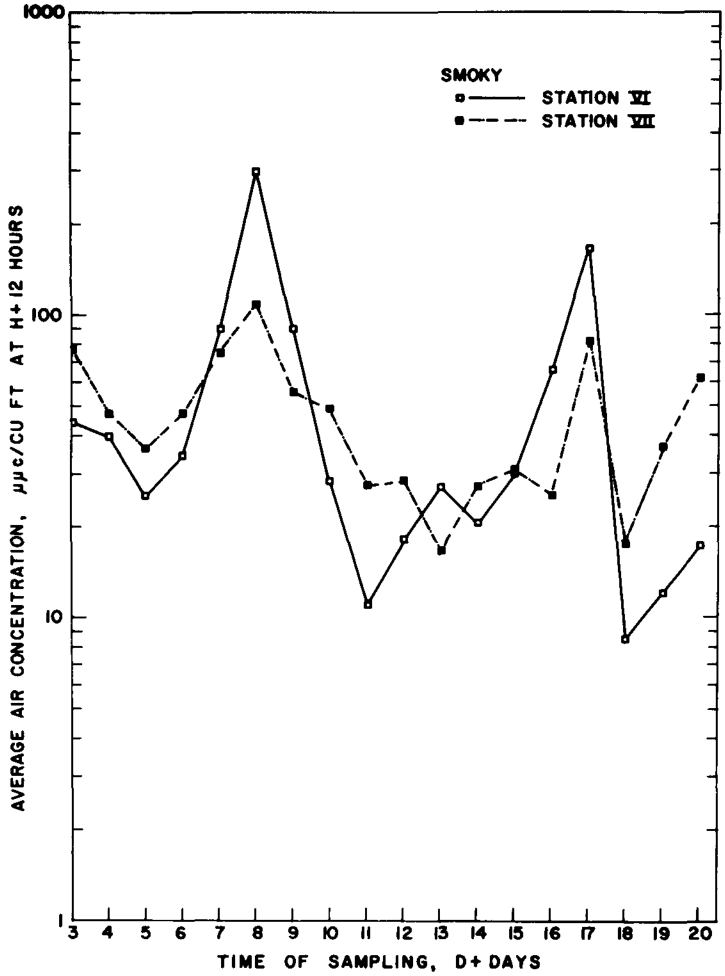

FIGURE 6.7 Average Radioactive Aerosol Concentrations at Smoky Persistence Stations from D + 3 to D + 20 Days.

TABLE 6.11 Persistence of Airborne Radioactivity in the Smoky Fallout Pattern

	Fission Product Concentration in Air, pc/ft^3 at H + 12 hrs.									
	Station VI					Station VII				
	Daily Sampling Period, hr					Daily Sampling Period, hr				
Time D + Days	0400 to 1000	1000 to 1600	1600 to 2200	2200 to 0400	Daily Average	0400 to 1000	1000 to 1600	1600 to 2200	2200 to 0400	Daily Average
3	--	--	34.0	54.2	44.1	--	--	108	46.8	77.4
4	25.3	89.2	21.9	22.9	39.8	55.4	36.7	61.8	32.7	46.7
5	20.2	30.1	26.1	23.8	25.1	38.3	28.5	49.8	28.7	36.3
6	20.1	30.1	29.4	57.4	34.3	25.9	18.1	53.0	90.0	46.8
7	157	87.9	76.3	37.2	89.6	85.3	89.8	85.7	37.2	74.5
8	48.0	1,572[a]	6,212[a]	548	298	45.5	171	3,143[a]	1,592[a]	108
9	162	47.6	104	43.1	89.2	114	39.8	35.1	30.4	54.8
10	9.94	11.9	37.5	37.4	28.3	85.8	25.5	37.2	47.4	49.0
11	9.29	7.31	17.6	9.92	11.0	51.1	19.6	19.8	20.1	27.7
12	11.2	28.3	25.2	8.55	18.3	28.5	32.4[a]	--	--	28.5
13	40.9	17.4	31.2	18.6	27.0	--	12.4	22.0	15.8	16.7
14	9.57	21.6	29.2	21.3	20.4	18.1	17.8	26.3	46.1	27.1
15	18.8	27.1	38.8	34.5	29.9	17.8	20.4	23.1	62.3	30.9
16	55.9	112	78.5	14.9	65.3	25.9	27.5	26.0	22.1	25.4
17	107	460	88.2	16.3	168	30.2	149	127	22.7	82.2
18	9.39	8.71	--	7.21	8.43	15.2	15.4	17.1	20.6	17.1
19	5.30	27.8	7.47	8.66	12.3	10.8	24.0	62.7	49.4	36.7
20	7.29	29.2	24.9	8.27	17.4	36.2	75.4	77.8	53.3	60.7
Average	42.2	68.3	41.9	54.0	51.6	42.8	48.2	52.0	39.1	45.5

[a] Short exposure value not included in averages

6.2.7 Native Vegetation Contamination

Plant data are presented in this chapter because they help to describe a mechanical process which influences the fate and persistence of fallout debris. Procedures used to radioassay plant samples are described in Appendix A.

The degree of plant contamination was highly variable depending upon the species sampled. Where a single species (*Artemesia tridentata*) was serially sampled over an 18 day period, the decline in radioactive contamination was shown to closely follow the $T^{-1.2}$ beta decay exponent for beta activity from mixed fission products (Figures 6.8 and 6.9; see Table 7.1 for additional Smoky station locations). This decline in radioactive contamination was also true when other data from single species were examined or when enough different species were averaged together to mask the effects of extreme leaf characteristics.

The uniformity of the data suggests that the original level of particulate contamination at the time of fallout is maintained on the plant despite wind and rain action. A greater variation in radiation intensity would be anticipated if the contamination level were being maintained by redistribution processes. Therefore, decreases in radioactivity during the 18 day period appear to result principally from radioactive decay, although the possibility that decay measurements are not sensitive enough to measure low level redistributed contamination cannot be overlooked.

6.2.8 Persistence Area Contamination from Succeeding Detonations

Throughout the study effort on Shot Priscilla, there was no indication of additional contamination. However, on D + 8 of the Smoky study a low yield, 750 foot, balloon supported device (Shot Wheeler) was detonated which could have conceivably added radioactive material to PVI and PVII.

Little information on the fallout pattern from Shot Wheeler is available as contamination levels were too low to be monitored by survey instruments, but the U. S. Weather Bureau computed the "estimated axis of fallout" to be 15 to 20 miles south of PVI. Examination of this project's data obtained during this period shows that, although the gamma activity was not sufficient to produce a response on the PRAM, a small amount of additional contamination was recorded by both the granular collector and aerosol sampler. The granular collector data indicated a contamination level at least an order of magnitude lower than the original Smoky debris.

It must be noted that the D + 8 values shown in Figures 6.4 and 6.7 appear inordinately high because decay corrections based on the Smoky time of detonation were applied to the data. These high values were disregarded in computing the environmental decay rates. It is believed that the minute additional fallout recorded does not affect the validity of the conclusions drawn from data presented in this chapter.

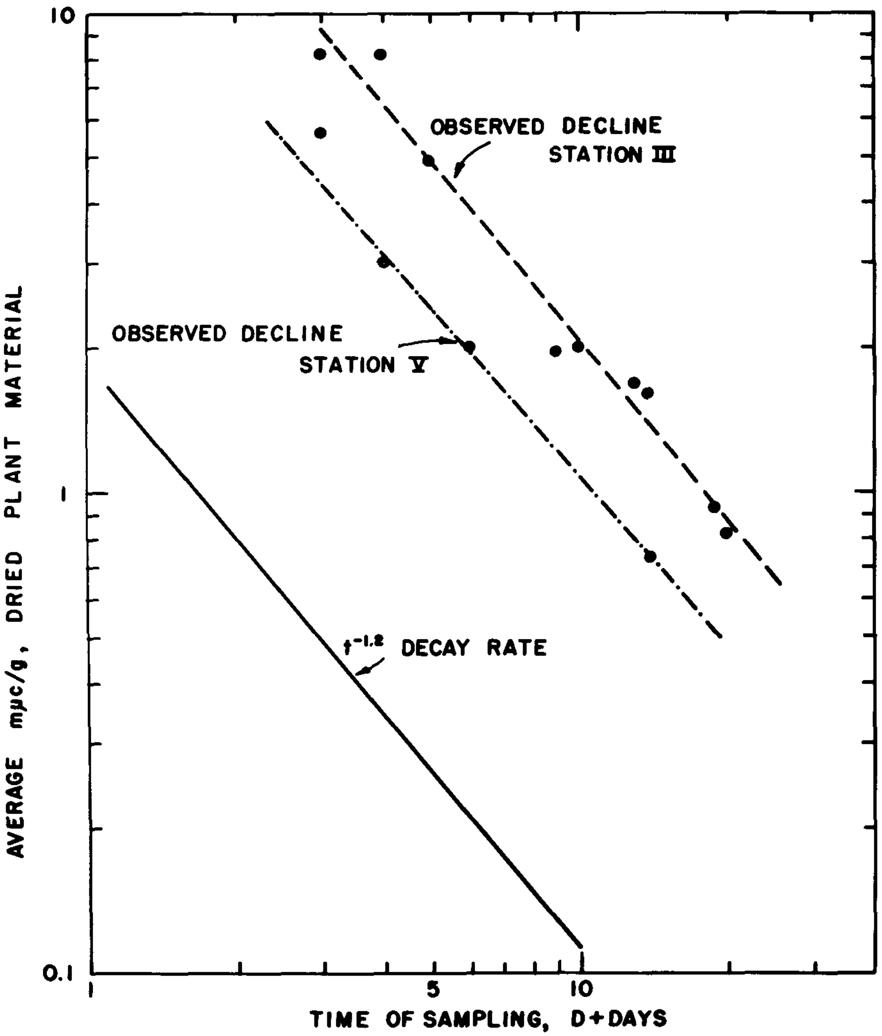

FIGURE 6.8 Persistence of Fallout Debris on Great Basin Sagebrush (*Artemisia tridentata*) from Selected Areas in the Priscilla Fallout pattern.

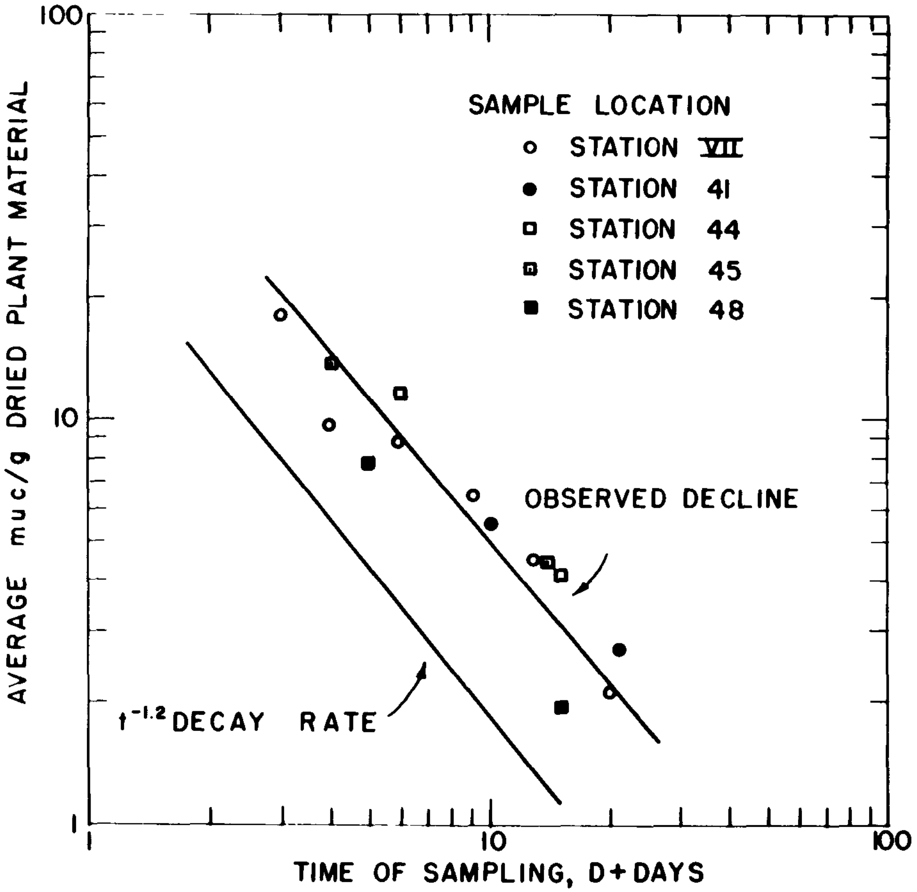

FIGURE 6.9 Persistence of Fallout Debris on Great Basin Sagebrush (*Artemisia tridentata*) from Selected Areas in the Smoky Fallout Patter.

No subsequent Plumbbob detonation contaminated the persistence study areas with activities greater than 0.5 mr/hr at H + 12.

6.3 DISCUSSION

6.3.1 Environmental Decay Versus Radioactive Decay

Environmental decay is the sum of the processes which alter the intensity of radioactive contamination. It includes the radioactive decay, erosion, and biological cycling. From the data presented above it is apparent that, over a 3 week period following fallout, the decline of radioactivity in the biotic environment is predominately due to radioactive decay rather than to redistribution by other environmental factors. This observation can be extended to at least one year after contamination on the basis of soils data obtained from Station VI and VII (Table 7.8) and soils data obtained during previous studies from the native Nye Canyon area bordering NTS (Reference 2).

"Persistence" as used in this report can have the implied meaning of "rate of change." The choice of the word seems particularly appropriate in view of the data demonstrating the permanence of concentrations of fallout debris in the environment and the implied slow rate of change in terms of months to years following contamination. However, particular attention must be given to the various time scales used to discuss persistence of fallout debris in the environment.

The persistence of fallout debris between D + 3 and D + 20 days is evidenced by the similarity between radioactive decay rates measured in the field and laboratory and by the redistribution data obtained following Smoky in which the maximum values were observed on D + 17 days. This peak occurred even though the general trend of redistribution was to decline with time following both Priscilla and Smoky.

The observation is interpreted to mean that fallout debris tends to become mechanically trapped in the environment and with time to become less and less available for redistribution. However, if a strong enough disturbance occurs (such as the storm on D + 17 days following Smoky), fallout debris less than 100 microns in size will tend to be redistributed at levels of particulate concentrations equivalent to the original contamination.

Observed aerosol concentrations between D + 3 and D + 20 days were similar following both Priscilla and Smoky despite significant differences in initial contamination. This suggests either that the fallout from Priscilla was relatively more susceptible to chronic suspension or resuspension than Smoky fallout or that the fraction of total fallout that contributes to aerosol concentrations was produced in similar quantities for both Priscilla and Smoky.

Since the aerosol concentration did fluctuate, it must be presumed that some quantity becomes resuspended by both thermal and mechanical disturbances. It was not possible on the basis of instrumentation used during the two studies to separate specifically the influences of wind, air temperature, and relative humidity. The lateral wind speed near the soil surface was very low compared to speeds measured at 3 feet above the surface in areas of moderate to heavy vegetative cover. Since redistribution of surface deposited fallout did occur, even though lateral wind movement appeared to be negligible at the soil surface, it appears that the vertical component of air movement should also have been instrumented.

Radiological monitoring done in the course of long term studies, 1 to 5 years following fallout contamination, has repeatedly shown that residual fallout contamination in relatively barren areas with significant expanses of exposed soil is characteristically higher about the base of bushes, obstacles, or crevices where wind or water eroded material tends to accumulate (Reference 3). It may be reasonably stated that the resultant effect of the local erosional forces should be to dilute the concentration of fallout debris on exposed soils and, therefore, reduce the intensity of the radiation field due to fallout.

An indication of the rate of this dilution is suggested in Table 6.8 where the mean value of fallout in surface soils is shown to be unchanged between D day and D + 300 days. The coefficient of variation, however, increased from 9.4 percent to 33.5 percent in the case of Station VI and from 14 percent to 43.8 percent in the case of Station VII. Since the sampling procedures and processing were similar for both groups of data, it is probable that the increase in ranges of values observed at D + 300 days was due to the scattering about of the initially deposited fallout. The fact that the mean level of contamination is unchanged suggests that, while the erosional processes are working, their effects are not significant in changing the concentration of fallout in these areas within 1 year following contamination. Calculations concerned with estimating dose, therefore, will be misleading if based to a significant degree upon the decrease of residual fallout by erosional factors in an area similar to those studied.

In terms of internal emitters the above relationships may not apply in biological accumulation of specific radionuclides.

6.3.2 Biological Implications

The particular significance of the persistence and redistribution of fallout debris to biological cycling lies in the potential availability of fallout debris to recontaminate forage plants, providing a continuous source of internal emitters to grazing animals together with a persistent low-level radiation field, the intensity and effects of which are dependent upon the proportions of medium- to long-lived fission products that are present (Chapter 4 and 5).

Even though redistribution of surface deposited fallout is a potential source of contamination to plants, the data collected following both Priscilla and Smoky indicated that the original fallout contamination was still on the plant during the period D + 3 to

D + 20 days despite wind and rain action. Had redistribution contributed significantly to plant contamination, the uniform decay rate that was observed would not be anticipated Therefore, the importance of redistribution in the secondary contamination of vegetation probably decreases with time as the foliage originally contaminated with fallout is replaced by new growth.

6.4 SUMMARY

1. Four persistence study stations were maintained on the midline of Priscilla fallout and two on the midline of Smoky fallout pattern.

2 Maximum air temperature, minimum relative humidity, and maximum air movement occurred at about 1300 hours each day. Minimum air temperature, maximum relative humidity, and minimum air movement occurred at about 0300 hours each 2 hour period.

3. Wind speed was negligible at 6 inches above the soil surface as compared with speeds 36 inches above the soil surface in areas with normal to dense vegetation cover, wind speeds were approximately equal at the two measurement heights in areas having sparse vegetation.

4. Radioactive decay measured in the field was similar to the decay of comparable fallout samples measured in the laboratory.

5. Attenuation of gamma radiation was measured as 15.7 percent at 18 inches and 27 2 percent at 36 inches, of the radiation at one inch, using film badge type dosimeters Beta attenuation similarly was measured as 28.6 percent at 18 inches and 44.2 percent at 36 inches, of the beta radiation measured at 1 inch above the soil surface.

6. Fallout debris deposited on the soil surface tended to become mechanically trapped, the amount redistributed declining with time. Strong winds, however, caused material to be redistributed at concentrations equal to the initial contamination especially in areas having a sparse vegetative cover.

7. The concentration of fallout debris in the surface inch of soil at two stations contaminated by Smoky Shot did not significantly change between D + 3 days and D + 300 days.

8. Particles 44-88 microns in diameter contributed an average of 9.7 percent of the total redistributed fallout following Priscilla as compared to 21.0 percent following Smoky. Particles less than 44 microns in diameter contributed an average of 85.8 percent following Shot Priscilla compared to 68.3 percent following Shot Smoky.

9. Aerosol concentrations were similar following both Shots Priscilla and Smoky despite significant differences in initial contamination.

10. The original fallout contamination of native plant material persisted through the 18 day period following Shots Priscilla and Smoky.

REFERENCES

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2. J. W. Neel, unpublished data, Atomic Energy Project, UCLA.

3. A. W. Bellamy and others; "The 1948 radiological and biological survey of areas in New Mexico affected by the first atomic bomb detonation", USAEC Report UCLA 32, November 1949, Atomic Energy Project, School of Medicine, University of California, Los Angeles, Unclassified.

CHAPTER 7

BIOTIC AVAILABILITY OF FALLOUT DEBRIS TO INDIGENOUS ANIMALS AND PLANTS

Earlier work during and after previous test series at NTS, reviewed in Section 1.2 and preceding chapters of this report, furnish information on the distribution, quantities, and properties of the fallout. Solubility characteristics and particle size data furnish some basis for estimating the availability of fallout debris to the biota.

However, biological availability of radionuclides associated with fallout deposited in the biosphere is modified by physical and chemical soil characteristics as well as by other variables. Therefore, it becomes important when evaluating potential hazards to determine the fraction of available radioactive material that actually is accumulated by various animals and plants in the local environment.

Since the conditions of detonating nuclear devices alter the fallout properties as well as the quantities of debris deposited in areas under study, biological uptake can be used as one means of comparing the relative availability of the debris from the different nuclear devices, such as balloon and tower mounted shots.

It has been well documented that animals grazing in fallout areas will accumulate radionuclides (Chapter 1). The purpose of this study is to document the relative biological availability of several radionuclides from fallout debris as a function of the characteristics of detonation and contamination. It would be expected that the amount of fission products metabolized by any particular animal will also be a function of the behavior and physiology of that species.

7.1 PROCEDURES

Native rodents (principally Dipodomys sp.) were collected using treadle type, metal box traps. Jackrabbits (Lepus sp.) were collected by shooting with .22 caliber rifles. All rodents were sacrificed immediately upon trap recovery by placing the trap, which contained the animal, on dry ice in an ice chest. All animals were packaged in dry ice and shipped to the UCLA Laboratory. The animals were autopsied to provide samples of skin, lung, liver, kidney, muscle, and bone that were assayed for total beta activity. Thyroid tissues were placed in stainless steel planchets, macerated, moistened with sodium thiosulfate, gently dried, and assayed for beta and gamma activity. When the beta activity was adequate for radiochemical determinations, selected samples were further characterized in terms of radionuclides of barium, cerium, cesium, ruthenium, strontium, yttrium, and zirconium. (It should be noted that Sr^{90} was not specifically identified). Certain thyroid samples were analyzed for radioiodine by decay and energy measurements.

Bulk plant samples were dried at 70 °C at the UCLA Laboratory, ground to pass a 20 mesh screen, and assayed for beta radioactivity.

These procedures are described in detail in Appendix A.

7.2 RESULTS

7.2.1 Fission Product Accumulation in Native Mammals

The accumulation of fission products by native rodents and lagomorphs sampled from various locations within fallout patterns was documented for five detonations during Operation Plumbbob, i.e., Boltzmann (Figure 2.1), Priscilla (Figure 2.3), Diablo (Figure 2.5), Shasta (Figure 2.6), and Smoky (Figures 2.7a and 2.7b). The sampling station locations and measurements of fallout contamination (as determined by Projects 37.2 and 37.2a) are described in Table 7.1.

The levels of beta activity from mixed fission products (MFP) and specific radionuclides present in tissues of animals sampled from the Boltzmann fallout pattern are presented in Tables 7.2 and 7.3; from the Priscilla pattern in Tables 7.4, 7.5 and 7.6; from the Diablo pattern in Tables 7.7 and 7.8; from the Shasta pattern in Tables 7.9, 7.10, 7.11 and 7.12; and from the Smoky pattern in Tables 7.13, 7.14 and 7.15.

Thyroid, liver, kidney, muscle, and bone values represent metabolized nuclides. The skin activity is predominantly attributable to external contamination by fallout particles on the pelt. The gastrointestinal tract (GI) and cecum samples include the associated gut contents, and the radioactivity in these cases is due to fallout particles that have reached the intestines through ingestion and perhaps by inhalation. The lung values are variable and usually quite low. While a possibility does exist that particulate contamination resulting from inhalation of fallout has occurred, it is more probable that the fluctuations noted in lung contamination reflect various degrees of hemorrhage in the pulmonary region occuring at the time of sacrifice and that the radioactivity reported is due to fission products in the residual blood and tissue fluids.

Jackrabbit tissues were used predominantly to determine concentrations of metabolized radionuclides because tissues from the smaller rodents, even when pooled, seldom provided a large enough sample for analysis. Individual jackrabbit tissues representative of a particular sampling time and location were selected for radiochemical analysis from available samples on the basis of the total beta count. The data, therefore, are useful in describing certain radionuclides that are present but are influenced, among other items, by the age and body weight considerations discussed below when used to measure levels of metabolized fission products changing with time.

Between 16.8 and 45.1 percent of the bone activity was routinely accounted for in all shots by Ba^{140} and $Sr^{89,90}$ occurring in ratios ranging from 1.46 to 6.73 in favor of

TABLE 7.1 Time of Fallout and Radioactive Levels in Areas Sampled by Project 37.1

Dose rate at time of fallout is calculated from monitoring values. Fallout time-of-arrival values were measured or estimated from trajectory analysis. ~, approximate or estimated.

Sta. No.	Miles from Ground Zero	Miles from midline	Estimated time of arrival, H + hr	Dose rate, mr/hr		Pct <44 micron fraction deposited	Beta Activity in <44 μ fraction, μc/sq ft (H + 12 hr)
				time of fallout	H + 12 hr		
Shot Boltzmann (D day: 28 May)							
1	36	0.0	1.4	2030	140	20	246
2	48	0.0	2.1	430	66	30	330
3	78	0.5 W	3.7	310	78	76	675
4	79	1.0 W	3.7	410	105	75	670
5	91	0.0	5.4	290	~120	--	--
Shot Priscilla (D day: 24 June)							
I	68	0.0	4.5	70	22.5	80	26
8	84	12.0 N	6.7	5	~2.5	--	--
III	129	1.0 N	7.1	9	4.7	85	7.8
IV	155	2.0 N	9.5	1.3	~1.0	82	6.6
V	197	4.0 N	9.5	2.5	~2.0	78	4.9
Shot Diablo (D day: 15 July)							
10	10	0.0	2.5	8880	~1500	--	--
11	13	~2.0 S	2.9	3680	~700	--	--
12	20	~1.0 S	3.8	690	180	~20	~190
13	40	0.5 S	5.1	180	70	50	210
14	60	0.0	6.5	95	50	--	--
Shot Shasta (D day: 18 August)							
15	10.5	5.0 W	0.5	500	NS	--	--
16	14.6	1.3 W	0.7	5940	100	13	240
17	14.8	1.0 W	0.7	9320	177	13	347
18	15.3	0.3 W	0.8	11240	236	13	455
19	16.9	0.7 E	1.0	6780	217	12	418
21	31	4.5 E	2.0	680	~100	--	--
24	44	3.0 E	3.3	390	86	70	535
25	44	0.5 E	3.0	615	120	43	589
26	44	0.3 W	2.9	570	107	40	480
27	44	0.8 W	2.9	590	110	39	421
28	44	1.1 W	2.9	600	111	39	420
30	76	3.9 W	4.9	14	5	--	--
31	76	0.2 W	5.3	90	37	--	--
32	76	0.4 E	5.4	62	26	--	--
33	75	0.2 E	5.5	45	~20	--	--
34	74	3.5 E	5.6	30	14	--	--
35	172	0.0	13.0	4	~4	--	--
Shot Smoky (D day: 31 August)							
36	48	0.0	3.2	1200	250	16	1310
VI	99	0.0	4.5	170	55	38	260
VII	136	0.2 S	4.8	77	27	--	--
41	159	0.7 N	5.6	55	~24	48	100
49	282	1.5 N	19.0	2	~4	--	--

TABLE 7.2 Average Total Activity in Tissues of Native Animals, (Boltzmann Fallout Pattern)

See Table 7.1 for station information of fallout contamination. Tot/Rep, total No. of animals used for measurement/ No. of sample replications used for average activity value.

Sta. No.	Miles from GZ	No. in Sample Tot/Rep	Average nc/gm of Tissue at Time of Collection (D + 16 days)							
			Skin	GI Content	Lung	Thyroid	Liver	Kidney	Muscle	Bone
Jackrabbits (*Lepus*)										
3	78	1/1	25.5	4.71	0.053	545	0.355	0.169	0.039	0.252
5	91	1[a]/1	29.1	9.57	0.062	277	0.709	0.171	0.495	18.1
Kangaroo Rat (*Dipodomys*)										
1	36	2/1	5.69	0.527	0.043	126	0.103	0.061	0.081	1.18
3	78	5/1	22.4	4.32	0.117	769	0.538	0.327	0.268	5.00
4	79	4/1	8.89	3.56	0.078	98.6	0.591	0.218	0.218	4.98
5	91	5/1	21.8	1.32	0.069	284	0.115	0.083	0.156	0.974
Deer Mouse (*Permoyscus*)										
1	36	1/1	7.94	0.325	nil	334	nil	nil	0.028	nil
2	48	7/1	7.58	1.03	0.045	494	0.125	0.077	0.128	1.50
3	78	19/2	22.0	1.80	0.047	548	0.104	0.081	0.178	2.26
4	79	4/1	25.9	1.84	nil	287	0.021	nil	0.113	0.747
5	91	2/1	17.1	2.34	0.072	684	0.285	0.178	0.548	2.95
Pocket Mouse (*Perognathus*)										
1	36	1/1	13.0	0.531	0.026	327	0.087	0.053	0.084	0.764
2	48	1/1	10.5	0.078	nil	472	0.083	nil	0.188	0.460
3	78	6/1	46.5	1.34	--	209	0.125	--	0.118	0.596

[a] Juvenile (See Figure 7.3)

TABLE 7.3 Concentration of Radionuclides in Bone of Kangaroo Rats, (Boltzmann Fallout Pattern)

MFP, beta activity values corrected for tissue beta background activity. Radionuclide values may contain trace amounts from previous fallout. All values corrected to time of collection. D + 16 days. Sampling locations along midline of pattern.

			Average dis/min/gm of Tissue			
Sta. No.[a]	Miles from GZ	No. in Sample	MFP	Ba^{140}	$Sr^{89,90}$	Pct of MFP Activity
1	36	2	2,630	600	230	32
3	78	5	11,090	2,230	1,300	32
4	79	4	11,055	2,010	1,510	32
5	91	5	2,160	280	350	29

[a] See Table 7.1 for Station Radioactivity Levels.

TABLE 7.4 Average Beta Activity in Tissues of Jackrabbits, (Priscilla Fallout Pattern)

See Table 7.1 for station information of fallout contamination. NS, not significant.

Time of Collection, D + day	Dose Rate, mr/hr	No. Sampled	Average nc/gm of Tissue at Time of Collection Skin	Cecum	Lung	Thyroid	Liver	Kidney	Muscle	Bone
Station I (68 miles from GZ)										
3	0.64	1	7.95	9.97	0.148	377	6.59	0.638	0.071	0.206
7	--	2	4.38	8.20	0.111	64.1	0.468	0.105	0.014	1.16
9	0.17	4	1.85	2.22	0.052	109	0.312	0.057	0.011	0.214
13	0.10	4	2.53	2.33	0.054	61.6	0.149	0.034	0.013	1.22
20	0.04	3	1.15	1.10	0.039	14.0	0.069	0.030	0.003	1.38
Station III (129 miles from GZ)										
3	0.26	4	7.39	3.97	0.387	234	2.25	0.182	0.042	1.46
4	--	1	11.3	2.94	0.353	17.1	1.29	0.220	0.048	1.30
5	0.12	2	8.10	1.11	0.056	14.8	0.687	0.148	0.011	0.984
9	<0.05	3	1.77	0.988	0.020	52.4	0.264	0.011	0.023	1.19
13	nil	12	0.273	0.130	NS	10.1	0.011	0.004	0.001	0.321
20	nil	12	0.273	0.130	0.003	10.1	0.011	0.004	0.001	0.321
Station V (197 miles from GZ)										
3	<0.05	1	4.46	1.58	0.022	87.7	2.97	0.233	0.006	0.050
4	--	1	4.68	3.84	0.069	232	3.25	0.203	0.025	0.038
6	--	1	0.677	1.73	0.021	73.2	0.213	0.074	0.020	0.087
10	nil	1	0.924	0.251	0.005	6.89	0.058	0.004	0.004	nil
13	nil	3	0.275	0.239	0.004	11.5	0.016	0.003	0.002	0.142
14	nil	1	0.498	0.275	0.001	11.6	0.032	0.012	0.002	0.475
20	nil	3	0.071	0.152	0.003	6.85	0.020	0.003	nil	0.422

TABLE 7.5 Concentration of Radionuclides in Bone of Jackrabbits, (Priscilla Fallout Pattern)

Total beta activity (MFP) values corrected for tissue background beta activity. Some radionuclides may contain trace amounts from previous fallout. See Table 7.1 for station radioactivity levels. NS, not significant.

	Sta I			Sta 8	Sta III	Sta V	
Miles from GZ	68			84	129	197	
Time of Collection, D + days	3	7	13	4	3	3	6
BONE, dis/min/gm of tissue[a]							
MFP	570	5030	3850[b]	2440	6330[b]	220	2020
Ba^{140}	95	980	960	340	1020	44	520
Ce^{141} + $Ce\text{-}Pr^{144}$	--	NS	300	290	NS	NS	NS
$Cs^{136,137}$	--	--	NS	--	--	--	--
$Ru^{103,106}$	--	--	--	--	--	--	--
$Sr^{89,90}$	27	470	340	140	290	7	150
Y^{91}	--	320	66	37	8	3	20
Zr^{95}	--	14	2	NS	NS	NS	5
Pct Radionuclide Activity Accounted for	21	36	44	33	21	24	34

[a] dis/min/gm tissue corrected to time of collection.

[b] Results are average of tissues from two animals; all other values based on one animal per sample.

TABLE 7.6 Average Beta Activity in Tissues of Kangaroo Rats, (Priscilla Fallout Pattern)

See Table 7.1 for station information of fallout contamination. Tot/Rep, total number of animals used for measurement per number of sample replications used for average activity value. ND, activity not detected.

Time of Collection, D + Day	Dose Rate, mr/hr	No. in Sample, Tot/Rep	Average nc/gm of Tissue at Time of Collection							
			Skin	GI Content	Lung	Thyroid	Liver	Kidney	Muscle	Bone
Station I (68 mi from GZ)										
3	0.64	17/4	17.5	3.43	0.075	404	0.696	0.237	0.060	0.559
5	0.37	29/6	7.46	1.99	0.043	83.6	0.442	0.176	0.034	0.477
9	0.17	13/3	9.89	1.05	0.048	153	0.117	0.103	0.024	0.287
13	0.10	23/5	4.62	0.587	0.024	59.5	0.057	0.017	0.046	0.480
20	0.04	26/5	1.63	0.183	0.009	13.1	0.008	0.011	0.012	0.153
Station III (129 mi from GZ)										
3	0.26	16/3	6.47	0.726	0.031	96.7	0.566	0.233	0.020	0.086
5	0.12	7/2	2.96	0.312	0.008	187	0.112	0.054	0.009	0.033
9	0.05	8/1	2.31	0.150	0.010	39.1	0.071	0.020	0.006	0.077
13	0.03	5/1	0.894	0.058	0.002	18.4	0.011	0.001	0.001	0.008
20	ND	1/1	0.370	0.001	0.003	12.4	0.009	0.003	nil	0.005

TABLE 7.7 Beta Activity in Tissue of Native Animals, (Diablo Fallout Pattern)

See Table 7.1 for station information of fallout contamination. Tot/Rep, total number of animals used for measurement per number of sample replications used for average activity value.

Sta. No.	Miles from GZ	No. in Sample Tot/Rep(b)	Average nc/gm of Tissue at Time of Collection (D + 5 days)							
			Skin	GI Content	Lung	Thyroid	Liver	Kidney	Muscle	Bone
Jackrabbit (Lepus)										
11	13	1/1	165	90.6	1.02	788	6.61	0.49	0.56	12.3
12	20	1/1	197	38.1	1.93	396	7.08	0.59	0.18	5.54
14	60	2/2	47.1	48.5	0.32	245	1.70	0.41	0.56	0.56
Kangaroo Rat (Dipodomys)										
10	10	9/2	362	60.1	1.31	1,126	10.9	2.19	1.78	7.64
11	13	20/4	101	20.6	0.19	456	2.44	0.38	0.46	1.87
12	20	16/3	130	26.6	0.46	232	3.48	0.61	0.57	1.77
13	40	34/7	40/6	11.3	0.13	124	1.00	1.85	0.18	0.54
14	60	2/2	32/6	13.8	0.58	77.7	0.44	1.18	0.59	1.91
Deer Mouse (Peromyscus)										
10	10	58/6	1647	160	2.24	2,472	14.9	4.46	8.15	11.3
12	20	12/2	293	40.4	0.81	10,017	18.5	4.89	3.88	9.28
14	60	23/8	40.5	10.5	0.53	71.1	3.0	1.01	0.76	1.43

TABLE 7.8 Concentration of Radionuclides in Tissues of Native Animals, (Diablo Fallout Pattern)

Total beta activity (MFP) values corrected for tissue background beta activity. Some radionuclides may contain trace amounts from previous fallout. See Table 7.1 for station radioactivity levels. Dis/min/gm values corrected to time of collection, D + days.

	Kangaroo Rat		Woodrat		Deer Mouse	
Station No/miles from GZ	10/10		10/10		10/10	
Kind of Tissue	Bone	Muscle	Bone	Muscle	Bone	Muscle
No. of Animals in Sample	2	2	2	2	58	58
Activity, dis/min/gm of tissue						
MFP	13,420	4,060	55,800	8,510	30,930	22,180
Ba^{140}	2,650	405	14,680	1,310	7,220	2,270
Ce^{141}+Ce-Pr^{144}	320	--	490	160	1,550	875
Cs^{136,137}	--	21	9	74	7	86
Ru^{103,106}	--	24	270	53	150	96
Sr^{89,90}	600	32	2,000	140	1,150	180
Y^{91}	260	68	450	74	440	400
Zr^{95}	23	75	7	6	95	--
Pct Radionuclide Activity Accounted for	29	15	31	21	34	18

	Kangaroo Rat		Jackrabbit	
Station No/miles from GZ	12/20		12/20	
Kind of Tissue	Bone	Muscle	Bone	Muscle
No. of Animals in Sample	None	15	1	1
Activity, dis/min/gm of tissue				
MFP	--	1,575	19,080	380
Ba^{140}	--	200	4,150	250
Ce^{141}+Ce-Pr^{144}	--	112	19	33
Cs^{136,137}	--	19	--	11
Ru^{103,106}	--	18	35	6
Sr^{89,90}	--	15	650	25
Y^{91}	--	38	110	15
Zr^{95}	--	6	--	6
Pct Radionuclide Activity Accounted for	--	26	26	91

TABLE 7.9 Beta Activity in Tissues of Jackrabbits, (Shasta Fallout Pattern)

See Table 7.1 for station information of fallout contamination.

Sta. No.	Time of Collection, D + day	Miles from GZ	Miles from Midline	No. Sampled	Average nc/gm of Tissue at Time of Collection							
					Skin	Cecum	Lung	Thyroid	Liver[a]	Kidney[a]	Muscle	Bone
21	D-day	31	4.5 E	1	1244	239	0.796	--	0.530	0.259	0.579	1.69
25		44	0.5 E	2	2590	437	0.989	--	0.680	0.692	1.20	0.794
28		44	1.1 W	1	750	734	1.17	--	--	0.377	2.32	2.82
15	D + day	10.5	5.0 W	1	245	158	0.210	7,877	384	0.199	0.792	
16		14.6	0.3 W	2	357	150	0.215	--	0.504	0.153	1.60	1.10
18		15.3	0.3 W	1	584	327	0.519	--	0.800	0.271	0.432	1.22
19		16.9	0.7 E	2	490	223	0.289	4,567	0.573	0.168	0.932	2.27
27		44	0.8 W	1	903	383	0.348	--	0.99	0.390	0.661	3.55
28		44	1.1 W	2	540	239	0.342	--	0.66	0.276	0.193	2.11
31		76	0.2 W	2	156	187	0.418	--	2.07	0.561	1.50	2.00
33		75	0.2 E	1	53.3	79.7	0.134	1,367	0.580	0.322	3.50	0.426
34		74	3.5 E	2	155	137	1.08	2,287	1.94	0.634	3.39	3.01
17	D + 2	14.8	1.0 W	1	185	122	0.124	--	0.181	0.166	3.19	0.376
19		16.9	0.7 E	2	140	53.1	0.141	1,257	0.322	0.118	5.04	1.97
24		44	3.0 E	1	161	127	0.235	1,421	2.47	0.459	1.48	2.58
25		44	0.5 E	1	144	144	0.525	4,751	2.52	0.306	2.79	3.91
26		44	0.3 W	2	463	202	0.504	12,846	1.45	1.02	2.44	6.48
28		44	1.1 W	2	310	157	1.12	--	2.12	1.80	2.27	6.72
30		76	3.9 W	2	8.86	4.87	0.091	458	0.124	0.060	0.056	0.237
31		76	0.2 W	1	29.7	25.7	0.515	--	0.351	0.635	0.072	0.252
32		76	0.4 E	2	127	69.4	0.250	--	2.26	0.478	0.193	2.11
35		172	0	7	23.5	54.5	0.400	2,809	147	7.81	0.610	3.02

[a] Decay correction made on basis of site of collection rather than shot average (Table 7.16).

TABLE 7.10 Concentration of Radionuclides in Tissues of Jackrabbits, (Shasta Fallout Pattern)

Total beta activity (MFP) values corrected for tissue beta background activity. Radionuclide values may contain trace amounts from previous fallout. Radionuclides are Ba^{140}, Ce^{141}+ $Ce\text{-}Pr^{144}$, $Cs^{136,137}$, $Ru^{103,106}$, $Sr^{89,90}$, Y^{91}, Zr^{95}. See Table 7.1 for station radioactivity levels. NS, not significant. Sample locations along midline of pattern.

Sta. No.	Miles from GZ	No. In Sample	Average dis/min/gm of Tissue at Time of Collection, D+2 days								Pct Radionuclide Activity Accounted For
			MFP	Ba	Ce	Cs	Ru	Sr	Y	Zr	
Bone											
19	16.9	2	3,140	519	22	2	15	200	48	--	26
26	44	3	5,200	910	74	9	23	186	59	10	24
31	76	2	4,430	842	22	4	17	174	56	7	25
35	172	3	6,170	848	25	10	22	134	45	6	18
Muscle											
19	16.9	2	3,970	107	27	3	3	9	14	--	4
26	44	3	6,020	178	34	6	5	19	23	8	5
31	76	3	4,800	142	28	5	7	10	18	12	5
35	172	3	1,550	126	26	4	4	10	14	8	13
Liver											
19	16.9	2	970	1	--	NS	NS	NS	--	--	NS
26	44	4	5,020	10	2	NS	NS	NS	2	NS	NS
31	76	3	3,660	2	NS	1	--	NS	NS	NS	NS
Lung											
19	16.9	2	380	12	--	2	NS	2	--	--	4
31	76	1	110	9	--	--	--	1	--	--	9

TABLE 7.11 Comparison of Beta Activity in Tissues of Native Animals, (Shasta Fallout Pattern)

See Table 7.1 for station information of fallout contamination. Tot/Rep, total number of animals used for measurement per number of sample replications used for average activity value.

Sta. No.	Miles from GZ	No. in Sample Tot/Rep	Average nc/gm of Tissue at Time of Collection (D + 2 days)							
			Skin	GI Contents	Lung	Thyroid	Liver	Kidney	Muscle	Bone
Jackrabbit (Lepus)										
31	76	1/1	29.7	25.7	0.515	--	0.351	0.635	0.072	0.252
35	172	7/7	23.5	54.5	0.400	2809	147	7.81	0.610	3.02
Kangaroo Rat (Dipodomys)										
31	76	21/4	36.3	7.52	0.020	507	0.158	0.046	0.203	0.519
35	172	108/21	9.55	7.62	0.078	1369	18.5	2.12	0.057	0.244
Mice (2 Species)										
31	76	3/1	51.3	5.45	0.051	1093	0.295	0.178	0.163	1.06
35	172	36/3	38.4	3.74	0.126	1393	15.0	2.24	0.121	0.422

TABLE 7.12 I^{131} and I^{133} in Thyroid of Jackrabbits, (Shasta Fallout Pattern)

See Table 7.1 for station radioactivity levels. Measurements made by single channel spectrometer using a 2 inch NaI crystal.

Sta. No.	Miles from GZ	Time of Collection H + hr	No. of Animals Sampled	Pct at H + 72 hrs			Ratio I^{133}/I^{131}	
				I^{131}	I^{133}	Activity Accounted for	Observed at H + 72 hrs	At Time of Collection
21	31	17	1	33	51	84	1.6	7.0
26	44	18	3	23	63	86	2.7	12
19	17	42	3	20	67	87	3.3	8.0
26	14	42	3	17	65	82	3.8	8.7
31	76	41	3	17	66	83	3.9	9.1

TABLE 7.13 Beta Activity in Tissues of Jackrabbits and Kangaroo Rats, (Smoky Fallout Pattern)

See Table 7.1 for station information of fallout contamination. Tot/Rep, total number of animals used for measurement per number of sample replications used for average activity value. ND, activity not detected.

Time of Collection, D + days	Dose Rate, mr/hr	No. in Sample Tot/Rep	Average nc/gm of Tissue at Time of Collection							
			Skin	Cecum	Lung	Thyroid	Liver	Kidney	Muscle	Bone
Jackrabbits (*Lepus*)										
Station VI (99 miles from GZ)										
3	9.5	1/1	100	21.4	0.986	280	2.45	0.142	0.151	0.258
12	ND	1/1	9.73	3.48	0.335	7.50	0.309	0.143	0.050	0.897
13	2.00	3/3	18.6	7.27	0.201	134	0.430	0.176	0.073	1.42
20	1.24	1/1	12.6	5.60	0.071	70.9	nil	0.113	4.11	1.06
Station VII (136 miles from GZ)										
3	2.91	4/4	39.3	13.2	0.451	497	6.95	1.02	0.330	0.952
5	1.79	5/5	35.1	9.39	0.252	138	2.13	0.662	0.249	1.14
9	1.10	4/4	10.8	2.69	0.190	89.5	0.488	0.141	0.129	1.50
13	0.70	1/1	12.2	3.63	nil	52.7	0.259	nil	0.035	0.755
20	0.48	5/5	3.57	0.982	nil	18.8	nil	nil	0.044	0.671
Kangaroo Rats (*Dipodomys*)										
Station VI (99 miles from GZ)										
3	9.5	25/5	77.0	9.42	0.113	216	2.47	0.836	0.390	0.520
5	6.18	33/7	26.2	8.29	0.149	124	1.77	0.657	0.213	0.430
9	4.88	25/5	11.1	2.32	0.056	31.1	0.235	0.157	0.063	0.247
13	2.00	44/9	10.6	1.93	0.074	29.3	0.189	0.142	0.118	0.372
20	1.24	46/9	6.01	1.32	0.057	29.2	nil	nil	0.051	0.234
Station VII (136 miles from GZ)										
3	2.91	25/5	18.8	1.09	0.065	186	0.665	0.301	0.229	0.470
5	1.79	39/8	24.2	2.23	0.070	86.2	0.434	0.172	0.089	0.484
9	1.10	55/11	6.88	0.725	0.039	53.6	nil	nil	0.039	0.361
13	0.70	58/12	6.41	0.603	0.041	25.7	nil	nil	0.043	0.391
20	0.48	30/6	1.87	0.198	nil	18.1	nil	nil	0.096	0.242

TABLE 7.14 Concentration of Radionuclides in Tissues of Jackrabbits, (Smoky Fallout Pattern)

Total beta activity (MFP) values corrected for tissue beta background activity. Radionuclide values may contain trace amounts from previous fallout. Radionuclides are Ba^{140}, Ce^{141}+Ce-Pr^{144}, $Cs^{136,137}$, $Ru^{103,106}$, $Sr^{89,90}$, Y^{91}, Zr^{95}. See Table 7.1 for station radioactivity levels. NS, not significant. Sample locations along midline of pattern.

Sta. No.	Miles from GZ	No. in Sample	Average dis/min/gm of Tissue at Time of Collection (D + 20 days)								Pct Radionuclide Activity Accounted for
			MFP	Ba	Ce	Cs	Ru	Sr	Y	Zr	
Bone											
36	48	1	20,420	6470	22	2	18	1700	125	4	41
VI	99	1	2,350	810	6	2	8	260	29	2	48
VII	136	3	1,810	610	4	2	4	200	34	--	47
41	159	1	1,280	390	3	11	6	80	25	NS	40
49	282	2	1,330	520	5	nil	NS	120	28	--	51
Muscle											
36	48	2	668	210	21	25	9	56	31	9	54
VI	99	1	90	19	2	19	1	5	2	NS	54
VII	136	2	170	18	8	--	2	3	2	2	20
41	159	1	64	12	3	--	1	3	6	NS	41
49	282	1	36	10	NS	--	NS	2	NS	--	37
Liver											
36	48	3	740	3	2	10	--	--	NS	--	nil
VI[a]	99	1	280	4	2	--	--	NS	3	--	nil
VII[a]	136	3	58	NS	NS	NS	--	--	NS	--	nil
49[a]	282	3	30	--	--	--	NS	NS	--	--	nil
Lung											
36	48	2	830	59	64	21	--	6	--	--	18
VI[a]	99	1	160	24	20	--	--	2	11	--	37
VII[a]	136	2	494	7	5	--	--	--	3	--	30
49[a]	282	3	38	3	4	--	--	NS	--	--	21

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[a] Questionable data due to low activity in sample aliquots.

TABLE 7.15 Changing Concentrations of Radionuclides in Tissues of Jackrabbits, (Smoky Fallout Pattern)

Total beta activity (MFP) values corrected for tissue beta background radioactivity. Radionuclides are Ba^{140}, Ce^{141}+Ce-Pr^{144}, Cs^{137}, $Ru^{103,106}$, $Sr^{89,90}$, Y^{91}, Zr^{95}. See Table 7.1 for location and fallout characteristics of this Station VII.

Time of Collection, D + Days	Dose Rate, mr/hr	Number of Animals	Forage[a], nc/gm	Average dis/min/gm of Tissue at Time of Collection								Pct Radionuclide Activity Accounted For
				MFP	Ba	Ce	Cs	Ru	Sr	Y	Zr	
Bone												
3	2.91	3	18.1	1900	507	7	6	2	96	10[b]	--	34[b]
5	1.79	2	9.5	3350	717	6	5	13	181	59[b]	--	29[b]
9	1.10	3	6.4	3670	748	10	7	7	222	38[b]	--	28[b]
20	0.48	3	2.1	1810	615	4	2	4	198	33[b]	--	47[b]
Muscle												
3	2.91	3	18.1	840	37	8	3	0.8[b]	4	5	2	7
5	1.79	2	9.5	930	159	21	4	6	8	13	7	23
9	1.10	2	6.4	350	35	12	4	4	5	15	6	23
20	0.48	2	2.1	170	18	8	--	2	3	2	2	20

[a] Dried Sage (Artemesia tridentata) believed to be primary forage of jackrabbits in this area. (Figures 7.8 and 7.9).

[b] Values only approximate.

Ba^{140}. Variations in this ratio followed no readily apparent pattern and did not appear to relate to the physical and chemical properties of the contaminating material discussed in Chapter 5.

In Boltzmann samples (Table 7.3) both Ba^{140} and $Sr^{89,90}$ reached maximum concentrations in the bone at 78 to 79 miles from ground zero (fallout time: H + 3.7 hours). In Priscilla samples (Table 7.5), Ba^{140} and $Sr^{89,90}$ reached maximum values in bone (D + 3 day collection) at 129 miles from ground zero (fallout time: H + 8.2 hours). In Shasta samples (Table 7.10) Ba^{140} was relatively low at 17 miles (fallout time: H + 1.0 hours), and remained more or less uniform between 44 and 172 miles distant (fallout times: H + 2.9 to H + 13.0 hours). In Smoky samples (Table 7.14), Ba^{140} and $Sr^{89,90}$ in the bone decreased in concentrations with distance from ground zero to 159 miles but increased at 282 miles.

Also Ba^{140} was the predominant isotope identified in muscle. Ce^{141}+ Ce-Pr^{144}, $Sr^{89,90}$, and Y^{91} were present in muscle in about equal concentrations of less than 5 percent each.

Specific isotopes present in liver and lung tissues were not accounted for to a significant degree by radionuclides of barium, cerium, cesium, ruthenium, strontium, yttrium, or zirconium.

With regard to any one location, data from Priscilla Station I (Table 7.5) and the comparable Smoky Station VII (Table 7.15) show that Ba^{140} and $Sr^{89,90}$ tended to reach maximum concentrations in the population between D + 5 and D + 7 days with a slight drop-off by D + 20 days. The observation is probably influenced by the selection of particularly 'hot' samples, and, in cases where such a time trend conflicts with the pattern of average beta activity in the bone which is derived from all of the samples available, the beta activity data should take precedent.

About 82 to 87 percent of the thyroid activity of jackrabbits collected on D day and D + 1 day of Shot Shasta was identified as I^{131} (17 to 33 percent) and I^{133} (51 to 67 percent) as determined at H + 72 hours (Table 7.12). Limitations of equipment did not permit identification of the remaining activity. Thyroid samples after D + 6 days contained only I^{131}.

7.2.2 Contamination of Forage Plants

The persistence of fallout contamination on forage plants is discussed in Chapter 6 and summarized in Figure 6.8 and 6.9. The relation of the degree of plant contamination to the changing levels of specific fission products in jackrabbit tissue following Shot Smoky is presented in Table 7.15.

7.2.3 Radioactive Decay in Animal Tissues

Thyroid tissue studied for radioactive decay indicated that, after D + 6 days, I^{131} was the only radionuclide present in the thyroid. However, between H + 17 and H + 42 hours I^{133} was shown to contribute as much as 67 percent of the observed activity (Table 7.12). It is possible that some I^{132} and I^{135} also was present as observed during previous test series (References 1 and 2). The fact that only 82 to 87 percent of the total activity was accounted for by I^{131} and I^{133}, however, is probably due to limitations in the resolution of the spectrometer system (See Appendix A).

Routine corrections of the observed counts in the thyroid to activity at the time of collection were made in two steps. First the counts observed after D + 6 days were adjusted to the time of collection on the basis of I^{131} decay. Second, the I^{131} value was increased according to the proportion of I^{133} that was predicted to be present (Reference 3). The assumption made in the second step was that no significant fractionation occurred between the two isotopes.

It was demonstrated that, with the exception of thyroid tissue, several nuclides were present in the animal's organs, which permitted the use of the mixed fission product decay expression. The error associated with the use of the mixed fission product expression is negligible when the interval between sampling and radioassay is short, i.e., when the ratio (t_2/t_1) is less than 10.

Beta decay constants (k) were determined empirically by following the rate of decay of 553 samples selected on the basis of tissue and shot (Table 7.16), of the position of the sampling site within the fallout pattern (Table 7.17), and of the time of collection (Table 7.18). The mean k values determined from samples collected following five detonations are presented in Table 7.16.

TABLE 7.16 Beta Activity Decay Constant (k) Determined in Seven Tissues of Animals Collected From Five Fallout Patterns

	Skin	Lung	Liver	Kidney	GI Content	Muscle	Bone	Mean k
Shot Boltzmann								
No. Samples	1	1	1	1	1	1	1	
k	-0.91	-0.68	-0.81	-0.81	-0.87	-1.31	-1.71	-1.01
Shot Priscilla								
No. Samples	12	12	11	10	12	13	10	
k	-0.96	-0.93	-2.49	-1.58	-0.92	-0.81	-0.99	-1.24
Standard Deviation	0.19	0.13	0.61	0.40	0.15	0.11	0.17	
Shot Diablo								
No. Samples	4	12	13	12	4	12	13	
k	1.14	-1.53	-2.93	-1.76	-1.08	-1.05	-1.06	-1.51
Standard Deviation	0.02	0.31	0.24	0.36	0.01	0.16	0.10	
Shot Shasta								
No. Samples	16	16	16	16	16	16	13	
k	-1.12	-1.10	-2.00[a]	1.49[a]	-1.09[a]	-0.90	-0.66[a]	-1.19
Standard Deviation	0.11	0.12	0.67	0.56	0.12	0.13	0.12	
Shot Smoky								
No. Samples	43	38	41	40	43	41	41	
k	-1.15	-1.56	-2.93	-2.78	-1.13	-1.10	-0.86	-1.64
Standard Deviation	0.04	0.45	0.58	0.48	0.08	0.13	0.07	
Mean k	-1.06	-1.16	-2.23	-1.68	-1.02	-1.03	-1.06	-1.32

[a] See Table 7.17

TABLE 7.17 Influence of Sampling Location Along the Shasta Fallout Pattern on Observed Beta Decay Constants (k) of Jackrabbit Tissues

Sta. No.	No. of Animals	Miles from GZ	Average Decay Constants (k) Liver	Kidney	GI Content	Bone
16 - 19	4	16	-1.40	-1.07	-1.17	-0.65
25 - 27	3	44	-1.46	-0.95	-1.05	-0.53
31 - 33	3	76	-1.54	-1.26	-1.20	-0.59
Mean			-1.47	-1.09	-1.14	-0.59
35	6	172	-2.81	-2.09	-1.06	-0.77
Mean (All Stations)[a]			-2.00	-1.49	-1.09	-0.66

[a] See Table 7.16

TABLE 7.18 Influence of Time of Collection on Beta Decay Constants (k) Determined in Animal Tissues, (Shot Smoky)

Location	Sampling time	Decay Constant (k) Skin	Lung	Liver	Kidney	GI Content	Muscle	Bone
Station 36	D + 3	-1.08 ± .04	-1.44 ± .16	-3.45 ± .26	-2.84 ± .25	-1.11 ± .04	-1.19 ± .07	-0.95 ± .06
	D + 20	-1.26 ± .01	-1.17 ± .05	-1.61 ± .12	-1.22 ± .19	-1.18 ± .03	-1.29 ± .15	-1.80 ± .05
Station VI	D + 4	-1.08 ± .02	-1.48 ± .15	-2.64 ± .28	-2.19 ± .28	-1.10 ± .03	-1.04 ± .09	-0.89 ± .07
	D + 12	-1.20	-1.09	-2.00	-1.42	-1.17	-1.03	-1.20
Station VIII	D + 4	-1.11 ± .05	-2.36 ± .93	-2.89 ± .64	-2.73 ± .47	-1.06 ± .07	-0.94 ± .11	-0.79 ± .17
	D + 9	-1.21	-1.19	-1.77	-1.57	-1.14	-0.91	-1.12

7.3 DISCUSSION

During Operation Plumbbob the agreement between observed levels of radioactivity in different animal species tended to be similar as evidenced in Figure 7.1. Generally the agreement of data obtained from different species of animals collected during previous weapons testing programs also has been good (References 1 and 2).

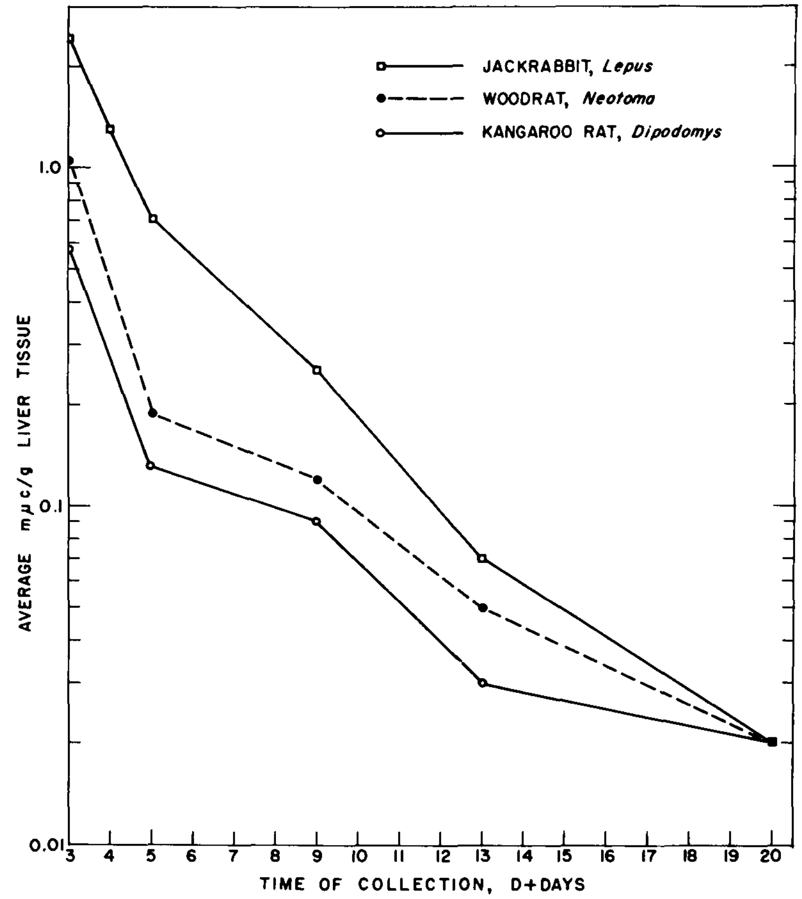

Figure 7.1 Comparison of Beta Radioactivity in Liver of Jackrabbit, Woodrat, and Kangaroo Rat and Time of Collection (Priscilla Station III).

The temptation to group data from several species into one set of values representative of the small mammal population in a given area was resisted, however, in view of occasional observations typified in Figure 7.2. In this latter case the kangaroo rate demonstrated significantly less fission product accumulation in the skeleton than either the jackrabbit or wood rat. Although the degree of accumulation is different, the various species are apparently using the contaminants physiologically in a similar manner since the rate of clearance appears similar. It should be noted that this kind of species difference was specifically looked for during previous studies and not found.

Where species differences are found they can be indirectly associated with differences in the concentration of ingested fallout debris as reflected by the radioactivity of the GI tract contents. Thus, daily differences in food habits and behavior characteristics of the indicator animals can make their accumulation of fission products very similar or very different. For this reason it is important that the patterns of fission product accumulation be determined separately for each species. Experience has shown that the patterns of accumulation will be similar but that the degree of accumulation can be very different.

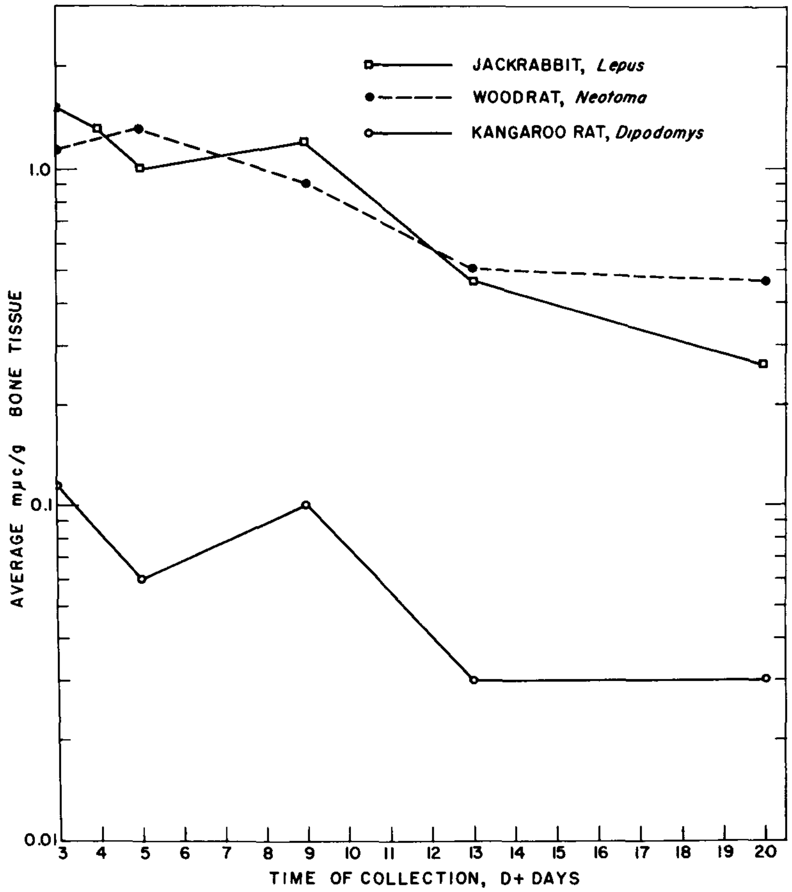

Figure 7.2 Comparison of Beta Radioactivity in Bone of Jackrabbit, Woodrat, and Kangaroo Rat and Time of Collection (Priscilla Station III).

7.3.1 Reliability of Animal Data

Data collected during three weapons testing programs, i. e., Upshot/Knothole (Reference 1), (Teapot Reference 2), and Plumbbob, indicate that the various genera of small mammals used as indicators of biological availability, i.e., jackrabbit (Lepus sp.), cottontail (Sylvilagus), kangaroo rat (Dipodomys), woodrat (Neotoma), pocket mouse (Perognathus), and deer mouse (Peromyscus), are alike both in the amount of and in the metabolic fate of fission products which they accumulate as a result of grazing in fallout contaminated environments. However, anomalies do occur and must be kept in mind in evaluating the data.

The reliability of radiological data collected from populations of a given species of native animal is dependent upon random sampling of the field population, precision of laboratory processing (including the selection of the proper radioactivity decay factors for each specific shot), sampling location, and tissue. These factors are further influenced by the age, food habits, and behavior of individual species and by the length of time an animal has been grazing in the contaminated area.

Regarding the random sampling of the field populations, a statistical evaluation of data collected from 7 jackrabbits and 123 kangaroo rats (grouped into 21 replicates) collected from within 0.5 mile of one another on the midline of the Shasta fallout pattern is shown in Table 7.19. The coefficients of variation for a specific tissue suggest that a reported value should be representative of the immediate population within a factor of two. Again, care must be exercised since the age of the animal can significantly influence the accumulation of the bone seeking nuclides as shown in Figure 7.3 and Reference 4.

TABLE 7.19 Variation in Total Activity in Various Tissues of Animals Collected on Midline of Shasta Fallout Pattern

	Activity at Time of Sampling (D +2days) nc/gm	Coefficient of Variation, Percent
Jackrabbit (7 animals)		
Bone	3.02 ±1.10	36.4
Muscle	0.607 ±0.240	39.3
GI Tract & Contents[a]	54.5 ±14.0	25.6
Skin[a]	23.5 ±10.3	44.0
Kangaroo Rat (21 replicates of 5 or 6 animals per replicate)		
Bone	0.244 ± 0.139	57.0
Muscle	0.057 ±0.031	54.4
GI Tract & Contents[a]	7.92 ±5.60	70.7
Skin[a]	9.55 ±6.16	64.5

[a] Activity due to radioactive fallout particles.

Despite this source of variation, the data from the seven rabbits summarized in Table 7.19 represent animals with body weights ranging from 1109 grams to 2290 grams. This implies that the age-to-weight influence on uptake is included in the coefficient of variation observed for the random sample. The majority of jackrabbits sampled during Operation Plumbbob weighed between 1500 and 2200 grams with a mean weight of approximately 1800 grams.

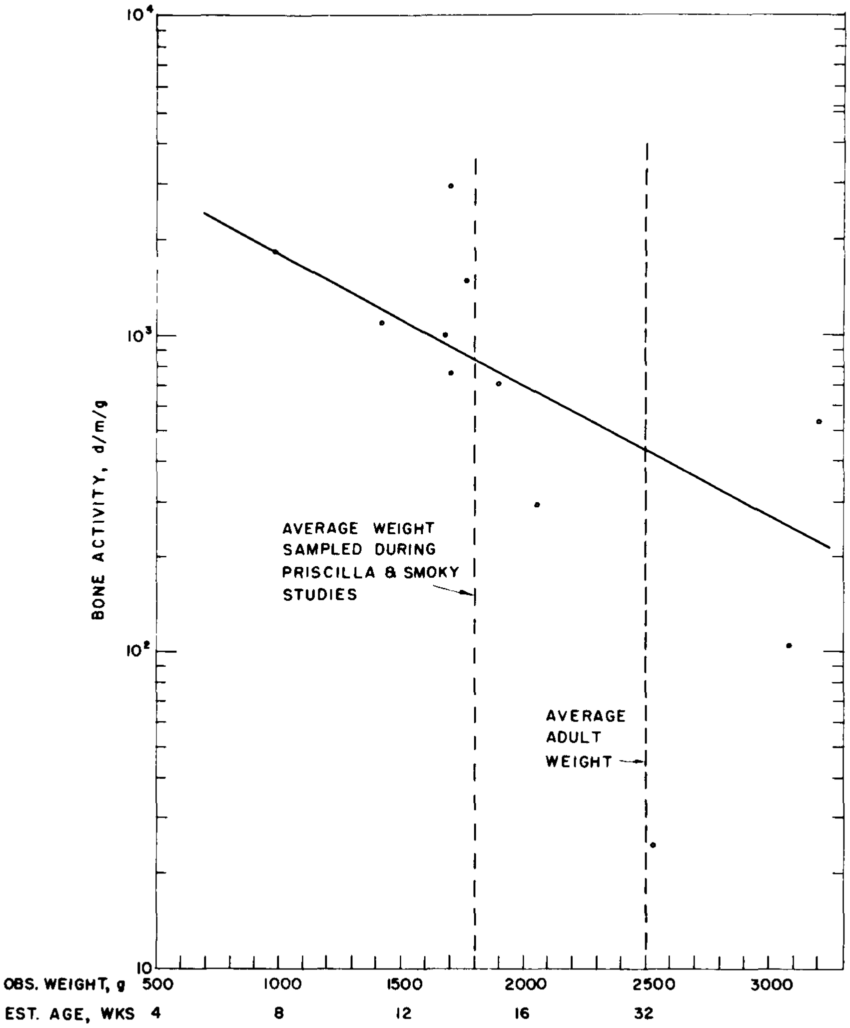

Figure 7.3 Influence of Age and/or Weight Upon Accumulation of Bone Seeking Radionuclides in Jackrabbits Collected D + 20 Days (Priscilla Station III).

Relatively few rabbits were sampled from any one location at any one time. As a result comparing the level of metabolized fission products as a function of fallout time-of-arrival or distance from ground zero in some cases cannot be done with jackrabbit data. A large mature animal may be sampled at one interval and a subadult at another. However, the jackrabbit samples were particularly valuable in supplying sufficient amounts of tissue and activity, for definitive radiochemical analysis. These restrictions do not apply to kangaroo rate data which were obtained almost exclusively from adult-weight animals but which in most cases did not provide large enough tissue samples for radiochemical identification of the contaminating isotopes.

The precision of laboratory processing and radioassay was tested by analyzing ten replications of bone, muscle, and GI tract and contents from a single jackrabbit. The coefficients of variation of total activity in tissue samples ranged from 1.2 percent for bone to 4.1 percent for the GI tract and contents.

With the exception of the liver and kidney values from Shot Shasta, the standard deviations of the decay constants represent coefficients of variation of 2 to 25 percent. For situations in which the k value approaches -1.0, a range of 25 percent would result in a variation of less than a factor of two assuming t_2/t_1 is less than 10. For situations in which the k value approaches -3.0, a 25 percent variation would still result in a value reliable within a factor of two, if t_2/t_1 does not exceed five. In approximately 90 percent of the samples processed, t_2/t_1 was less than five, and in only 5 percent did t_2/t_1 exceed ten. Thus, because t_2/t_1 was kept small, the maximum variation to be anticipated due to improper selection of decay constants is a factor of two.

Considering a maximum variation of 100 percent due to differences in the decay exponents, 5 percent variation due to laboratory processing, and 100 percent variation due to field variability, the data presented herein are representative of the relative fission product accumulation in specific animal populations within a factor of three with the majority of the data accurate within a factor of two.

7.3.2 The Biological Accumulation of Fission Products Related to the Position of the Sampling Site within the Fallout Pattern

A generalized concept of the fallout phenomenon as experienced at the Nevada Test Site considers three categories of fallout contamination differing in the distance from the point of detonation at which fallout occurs and/or the time after the event at which fallout is deposited. These categories are referred to as drop out, close-in, and tropospheric fallout (Figure 7.4). The radiation intensity in the pattern depends upon many factors, such as, the energy yield, the specific design of the device, the amount of inert material incorporated into the fireball, and the meteorological conditions (Chapter 2). As delineated by Program 37, the lateral limits of a fallout pattern from tower mounted shots were arbitrarily defined by the 1 mr/hr (at H + 12 hours) isopleths.

For these studies the length of the fallout pattern was chosen as a distance corresponding to a fallout arrival time of 12 hours after the detonation. The area receiving fallout between 1 and 12 hours after the detonations is referred to as close-in fallout and, depending upon the wind speed, may vary from less than 100 miles to several hundred miles in length.

It should be noted that, within the dimensions of close-in fallout, less than 25 percent of the radioactivity produced by above ground detonations is deposited; or, conversely, 75 percent of the radioactivity continues beyond the H + 12 hour distance. The fallout deposition beyond H + 12 hour distance is in ever lessening concentrations and is referred to as tropospheric fallout. For detonations supported by balloons, less than 2 percent of the produced radioactivity is deposited as close-in fallout.

Within this frame of reference, the biological sampling done during Operation Plumbbob took place at its closest point 10 miles from Shot Diablo ground zero and at its furthest point 322 miles from Shot Smoky ground zero. The majority of samples originated between 15 and 150 miles from various ground zeros (Table 7.1). The biological data, therefore, are particularly pertinent to the fate of close-in fallout.

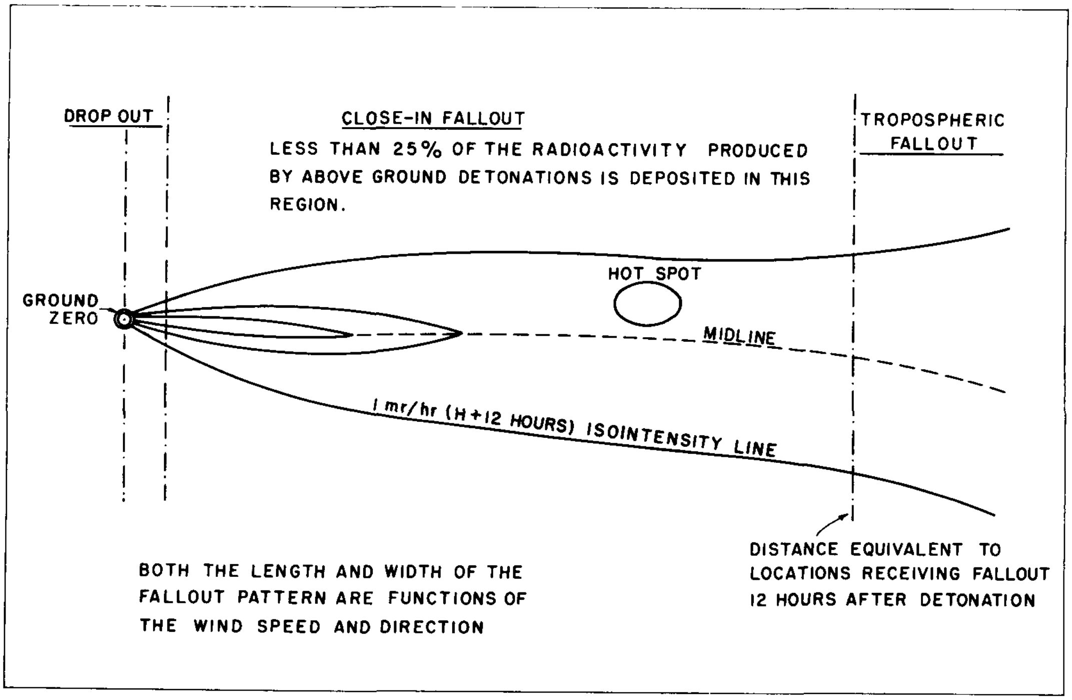

Figure 7.4 A Generalized Fallout Pattern Resulting from Kiloton Detonations at the Nevada Test Site.

Generally the accumulation of mixed fission products in any particular tissue is expected to decline with increasing distance from ground zero. For example, when the accumulation of mixed fission products (beta activity) in the skeleton of kangaroo rats and jackrabbits is tabulated with respect to distance of the sampling site from ground zero, the tendency for the concentration of fission products to decline with distance appears common to the five detonations documented with few exceptions (Table 7.20).

Distance from ground aero of a sampling location does not permit a realistic comparison of biologically available radionuclides from fallout from various shots. Consideration of other factors that influence the distribution of fallout in the biosphere is reflected when comparisons of accumulated activity in animals are made with respect to fallout time of arrival at sampling locations within different fallout patterns. Examples from Table 7.20 indicate this phenomenon. The radioactivity levels in kangaroo rat bone are nearly the same level from locations in which fallout from five shots arrived between H + 4.5 hours and H + 5.3 hours. The distance from ground zero of these sampling locations varied from 40 to 136 miles.

Knowing that in any tissue the level of fission products changes with time, some concern may be expressed regarding the comparison of radiation levels determined from samples collected at different times (e.g., Boltzmann D + 16 days versus Shasta D + 2

TABLE 7.20 Accumulation of Beta Activity (MFP) from Fallout Material in Bone from Kangaroo Rats and Jackrabbits with Respect to Distance from Ground Zero and Fallout Time of Arrival.

	Distance from GZ, miles	Fallout Time of Arrival, H + hours	Beta Activity, nc/gm of Tissue
Kangaroo Rats			
Shot Boltzmann (Time of Collection, D + 16 days)			
	36	1.4	1.18
	78	3.7	5.00
	79	3.7	4.98
	91	5.4	0.974
Shot Priscilla (Time of Collection, D + 13 days)			
	68	4.5	0.480
	129	7.1	0.008
Shot Diablo (Time of Collection, D + 5 days)			
	10	2.5	7.64
	13	2.9	1.87
	20	3.8	1.77
	40	5.1	0.54
	60	6.5	1.91
Shot Shasta (Time of Collection, D + 2 days)			
	76	5.3	0.519
	172	13.0	0.244
Shot Smoky (Time of Collection, D + 3 days)			
	99	4.5	0.520
	136	4.8	0.470
Jackrabbits			
Shot Priscilla (Time of Collection, D + 13 days)			
	68	4.5	1.22
	129	7.1	0.321
	197	9.5	0.142
Shot Diablo (Time of Collection, D + 5 days)			
	13	2.9	12.3
	20	3.8	5.54
	60	6.5	0.56
Shot Shasta (Time of Collection, D + 2 days)			
	16.9	1.0	1.97
	44	2.9	6.48
	76	5.4	2.11
	172	13.0	3.02

day data). If the radiation levels in the bone are corrected to a common sampling time for each shot, the relative change in activity with time does not change; but the absolute amount of radioactivity in the bone does, generally reflecting the degree of fallout contamination.

This latter refinement is not considered necessary for this discussion since our concern is with the relative biological accumulation.

A point of interest is a slight difference in accumulated activity in animals from patterns from the four tower-supported detonations and the single balloon-supported detonation (Shot Priscilla). The data points are admittedly too few; however, it would appear that the difference between the Smoky tower shot and Priscilla balloon shot corresponds to differences in the distribution and characteristics of the less than 44 micron fallout particles of the respective shots as described in Chapters 3 and 5. This observation is in support of a similar phenomenon documented in some detail during Operation Teapot (Reference 2) which relates uptake of fission products to the distribution of the less than 44 micron particle sizes.

With regard to the further influence of the position of the sampling site within the fallout pattern, attention must be given to the discontinuities that commonly occur in fallout deposition which, because of their insular nature, have come to be known as 'hot spots' (Figure 7.4). Generally the dose rate, which a fallout pattern specifically reflects, falls off sharply with distance. Occasionally, however, the occurrence of a hot spot will produce an anomaly.

Hot spots were identified in the Boltzmann pattern (Figure 2.1 and Table 7.20) at 78 miles from ground zero with a fallout time of H + 3.7 hours and in the Diablo pattern (Figure 2.3 and Table 7.20) at 60 miles from ground zero with a fallout time of H + 6.5 hours. In both cases the hot spots are reflected by high concentrations of beta activity in the bone tissues sampled from that area and this suggests that the degree of uptake by animals is directly related to the amount of fallout of less than 44 microns that is associated with an animals' diet during the acute phase of contamination. In these cases there appear to be no data indicating an unusual fractionation or distribution of isotopes within the fallout present; only that a higher percentage of the less than 44 micron fallout has occurred (Table 7.1 and Chapter 3).

There appears to be another kind of hot spot which is concerned with isotopic fractionation and is reflected by the burden of internal emitters metabolized by animals in local areas. This kind of hot spot does not necessarily correspond in location to the gamma radiation anomaly. Examples from Operation Plumbbob come from samples collected following Shot Shasta (Table 7.9). Bone, liver, kidney and thyroid tissues collected 172 miles from the Shasta ground zero (fallout time 13.0 hours, Figure 2.6) were 10 to 100 times higher than similar tissues sampled closer to ground zero.

Similar areas producing unusually high concentrations of radioiodine in thyroid were described during Operation Teapot (Reference 2) and of Sr^{89} in bone following Operation Upshot/Knothole (Reference 1) and Operation Teapot (Reference 2). The concept of hot spot must be broadened to include circumstances in which individual isotopes or tissues may show adherent fission product concentrations due to the physical and chemical nature of fallout debris.

7.3.3 Rates of Change in the Biological Concentrations of Fission Products

The influence of the first 20 days after fallout that an animal has been grazing in a fallout field is presented for Shot Priscilla, in Tables 7.4 to 7.6 and for Shot Smoky in Tables 7.13 to 7.15. These data reflect the biological fate of both total beta activity and specific radionuclides in animal populations sampled between D + 3 and D + 20 days.

In general all tissues show a decrease in total activity with increase in time after fallout at a rate similar to those reported during Operations Upshot/Knothole (Reference 1) and Teapot (Reference 2). The kangaroo rat data are most similar to earlier data and are believed to reflect the pattern of rate of turnover of total activity that would be expected for adult animals grazing in fallout fields. The jackrabbit data, while showing similar trends, are more variable. The variability is, in part, due to both the sample number and the wide range of total body weights represented in typical samples (Figure 7.3).

The relative persistence of specific isotopes present in various tissues were derived from selected samples of jackrabbits; therefore, the rates of change documented may be somewhat different than the rates shown for total beta activity in the statistically more valid kangaroo rat samples. The data pertaining to the relative abudance of certain radionuclides between D + 3 and D + 20 days are summarized in Figures 7.5, 7.6 and 7.7. They are useful in demonstrating that the skeletal accumulation of MFP in animals collected from Shot Priscilla (Figure 7.5) and Shot Smoky (Figure 7.6) are quite similar both in the amount and distribution of the specific isotopes identified. Muscle tissue (Figure 7.7 shows a much different proportion of the isotopes identified in the bone.

Further biological fractionation of MFP in animal tissue can be demonstrated by following (1) the rate of radioactive decay in the laboratory of isolated tissues sampled from the field at the beginning of any particular study, (2) the decline of radioactive content of tissues serially sampled from the field population, and (3) the rate of radioactive decay of fallout in the environment. The three rates of decline are remarkably similar for samples of skin, GI tract, and muscle. The decline of the radioactive content of liver tissue, which was serially sampled from the field population, and the rate of radioactive decay of isolated liver samples in the laboratory are also similar but deviate markedly from the rate of radioactive decay of fallout in the environment (Figure 7.8).

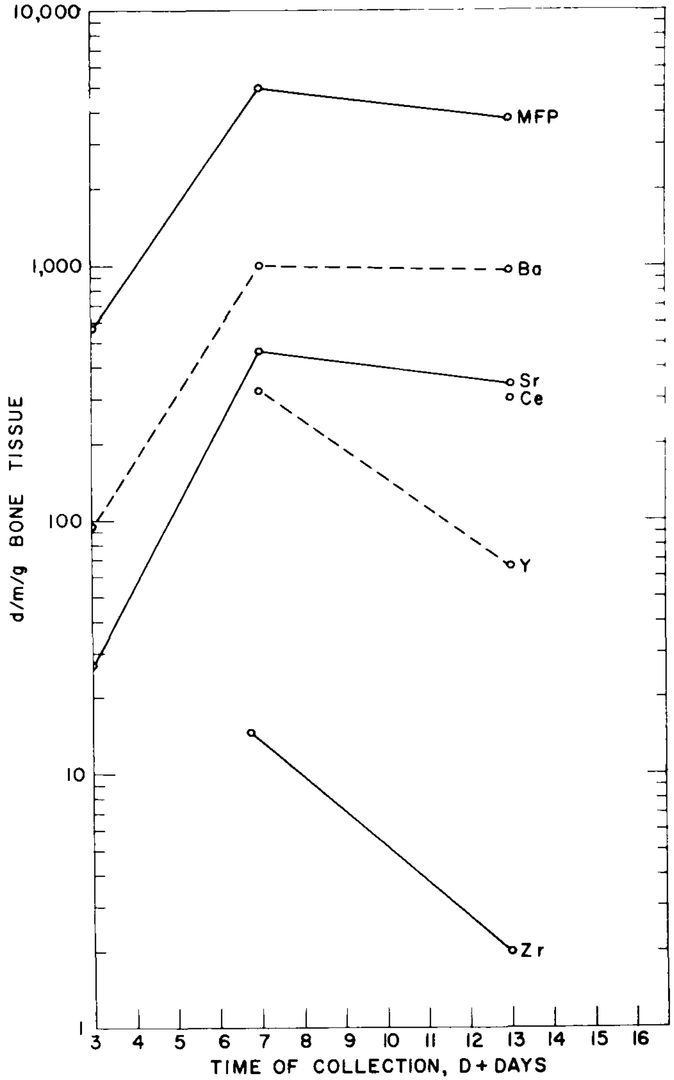

Figure 7.5 Radionuclides and Beta Activity(MFP) in Jackrabbit Bone as a Function of Time of Collection at Priscilla Station III.

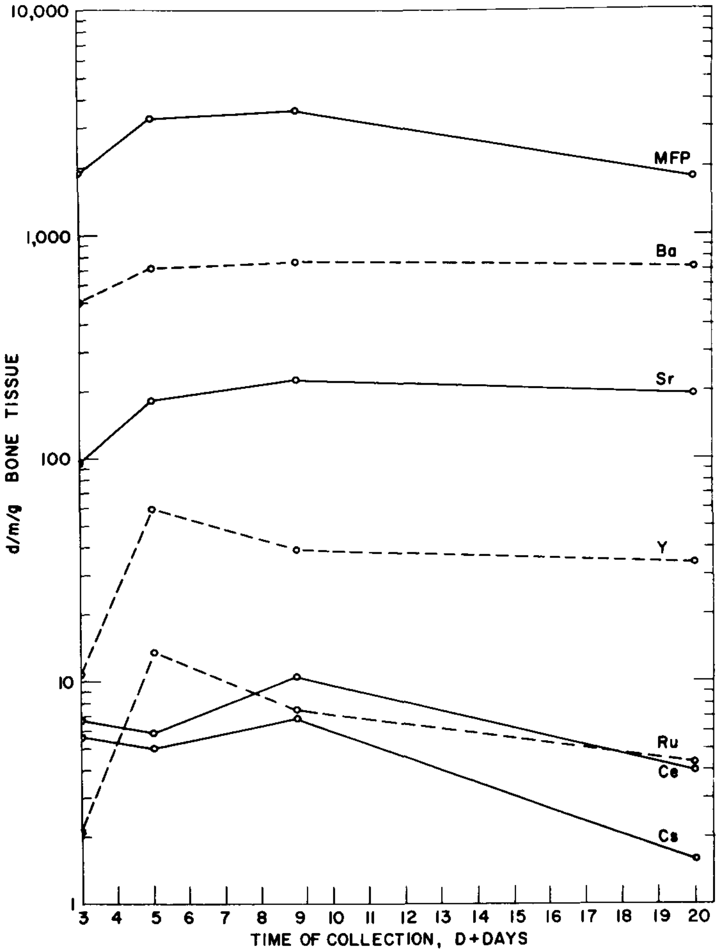

Figure 7.6 Radionuclides and Beta Activity (MFP) in Jackrabbit Bone as a Function of Time of Collection at Smoky Station VII.

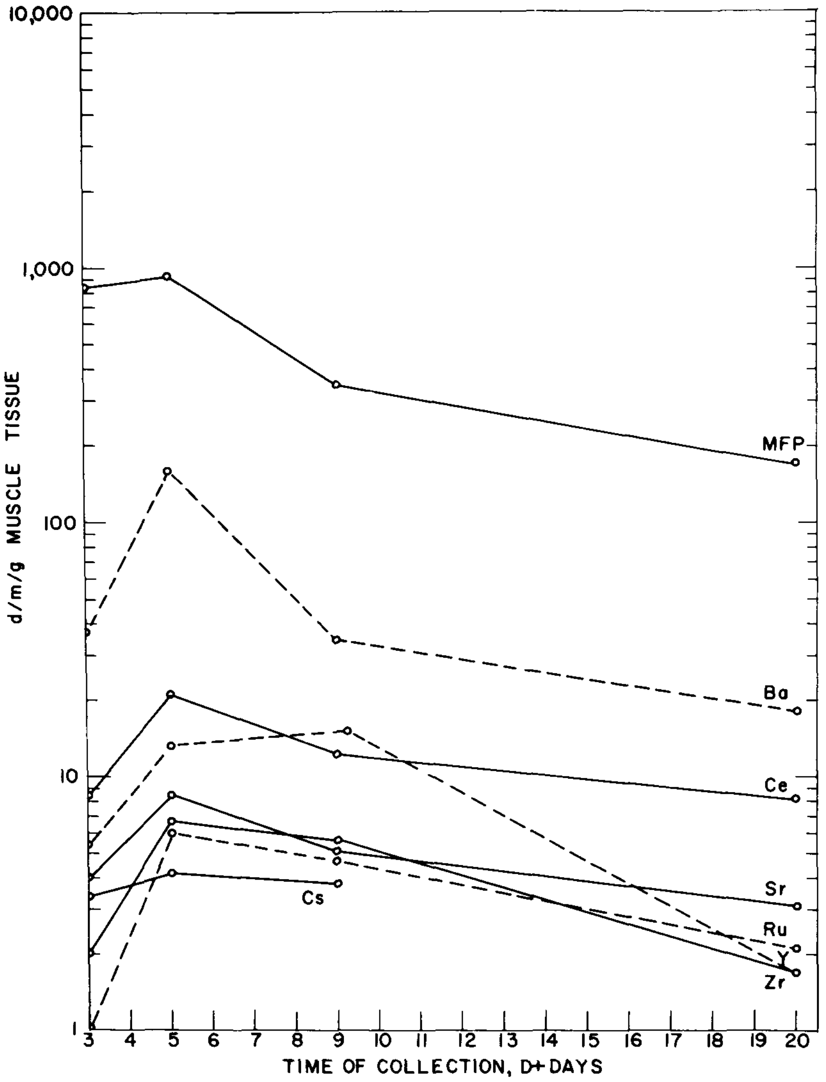

Figure 7.7 Radionuclides and Beta Activity (MFP) in Jackrabbit Muscle Tissue as a Function of Time of Collection after Shot Smoky.

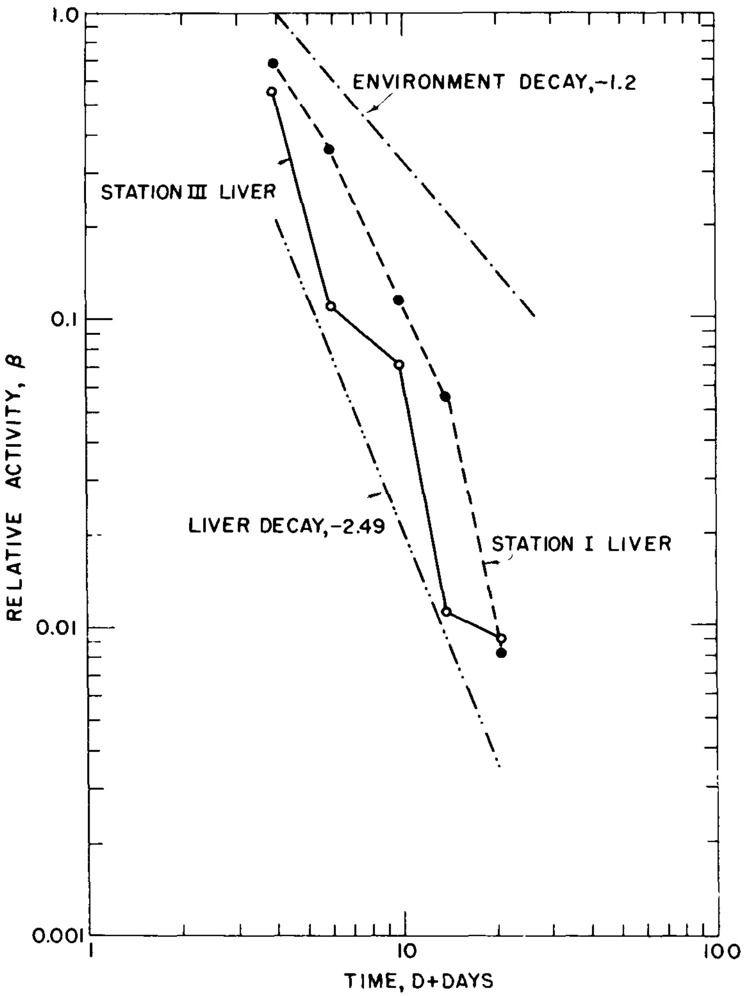

Figure 7.8 Comparison of Beta Decay of Jack-Rabbit Liver Tissue ($T^{-2.49}$), Liver Serially Sampled from Jackrabbit Population, and Decay Rate ($T^{-1.2}$) of Activity in Station Environment.

These data demonstrate the equilibrium between the tissue concentrations and the biologically available fission products in the environment. Similar relationships are not apparent for bone tissue and reflect the buildup or retention of specific isotopes (Figure 7.9). The data are supported by similar observations made during previous weapons testing programs (References 1 and 2).

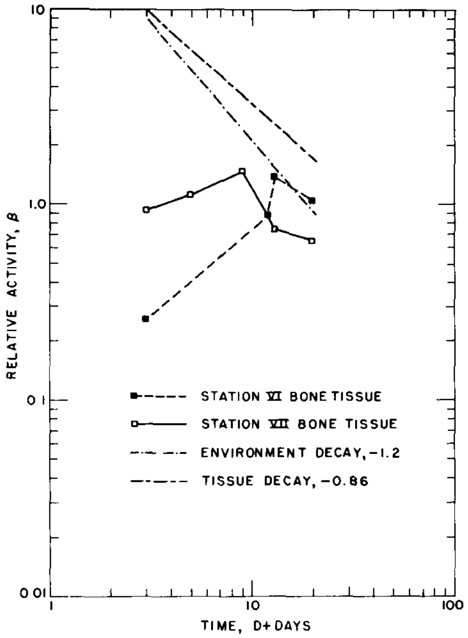

Figure 7.9 Comparison of Beta Decay of Isolated Bone Tissue ($T^{-0.86}$), Bone Tissue Serially Sampled from Animal Population, and the Decay Rate ($T^{-1.2}$) of Beta Activity in Station Environment.

7.3.4 The Influence of the Conditions of Detonation on the Biological Availability of Fission Products from Fallout

Regarding the physical and chemical properties of fallout debris, the utilization of the contaminants is dependent upon the radionuclides being in a soluble or digestible form. It is perhaps desirable to point out that this dependency occurs whether one is concerned with the leaching of radioactive materials through soil, with the uptake of fission products by plant roots or leaves, or with the metabolism of radioactive residues by animals. If the contaminants are not soluble, the effect of radioactive debris is essentially limited to an external radiation field of more or less rapidly declining intensity.

Stated another way, the potential hazard of metabolized radionuclides is dependent upon that portion of the fallout debris that is biologically available, i.e., digestible or soluble. For this reason considerable attention has been given to characterizing close-in fallout debris with regard to the factors which influence solubility (Chapter 5).

A comparison of the tower supported Shot Smoky (44 kt) and the balloon supported Shot Priscilla (37 kt), each at 700 feet, shows that the concentration of fallout at any one point was higher for Smoky. This may be summarized by stating that at distances corresponding to fallout times of H + 1 to H + 12 hours, Shot Smoky deposited 52 times more beta radiation and 14 times more of the less than 44 micron size fallout debris than Shot Priscilla. Within the limits of close-in (H + 12 hours) fallout, Shot Smoky deposited approximately 76 megacuries of beta radiation compared to 1.46 megacuries by Shot Priscilla (Section 3.3.5). Despite this difference in fallout deposition, the accumulation of fission products in the bones of animals sampled from the respective fallout patterns was similar.

At comparable stations, (Priscilla Station III and Smoky Station VII, Table 7.1) the degree of contamination in terms of microcuries per square foot of the less than 44 micron fractions was higher from Smoky fallout than from Priscilla fallout. As indicated in Table 7.21, the activity of the GI content of rabbits at these stations averaged 5.49 times greater for Smoky than for Priscilla during the 3 week study period. The liver activity averaged 3.19 times higher and the bone activity only 1.41 times higher for Smoky than for Priscilla samples. This is as would be predicted on the basis of the solubility of the respective fallout materials summarized in Chapter 5.

TABLE 7.21 Relative Accumulation of Total Activity in Tissue Samples from Jackrabbits Grazing in Areas Contaminated by Priscilla and Smoky Fallout (Priscilla Station III and Smoky Station VII)

Time of Collection D + days	GI Tract and Contents			Liver			Bone		
	Priscilla	Smoky	(S/P)[a] Ratio	Priscilla	Smoky	(S/P) Ratio	Priscilla	Smoky	(S/P) Ratio
	nc/gm Tissue			nc/gm Tissue			nc/gm Tissue		
3	3.97	13.2	3.33	2.25	6.95	3.09	1.46	0.95	0.65
4	2.94	--		1.29	--	-	1.30	-	--
5	1.11	9.39	8.46	0.69	2.13	3.10	0.98	1.14	1.16
9	0.99	2.69	2.72	0.26	0.49	1.85	1.19	1.50	1.26
13	0.67	3.63	5.40	0.06	0.26	4.71	0.40	0.76	1.91
20	0.13	0.98	7.55	0.01	--	-	0.32	0.67	2.09
Average Ratio			5.49			3.19			1.41

[a] Smoky/Priscilla

These data suggest that, despite the much larger deposition of fallout material by Shot Smoky, the amount of biologically available Ba^{140} and Sr^{89} is actually greater for Shot Priscilla. Thus, while the balloon supported detonation has effectively lowered the concentration of fallout deposition (and the resultant external radiation field), it has not significantly altered the degree of accumulation of some radionuclides (internal emitters) during the acute phase of fallout contamination.

Chronic tissue burdens can be influenced by the difference in level and nature of fallout reflected in the relative persistence of radioactivity in the bone of Priscilla and Smoky samples (Table 7.20). The Smoky-to-Priscilla bone ratios change from less than 1 to greater than 2. It is possible that this change reflects both the difference in concentration of the deposited fallout and its biological availability. The Priscilla debris, being more soluble, is more readily metabolized. The Smoky fallout, while less soluble, was more concentrated and gradually built up to higher concentrations in the animal population.

Apart from the exception discussed above in the comparison of the Smoky tower supported detonation and the Priscilla balloon supported detonation, the patterns for the utilization of mixed fission products by animals appeared to be similar for all detonations within the time period of these studies during Operation Plumbbob.

7.3.5 Review of Observations of Apparent Environmental Equilibrium and Biological Availability of Sr^{90} (1958-1961)

Apparent Environmental Equilibrium: In 1958 and 1959, jackrabbits were collected from Yucca Flat out to a distance of 400 miles. While most of these areas were contaminated during the Plumbbob Series, most (if not all) were contaminated to various degrees during previous test series.

The Sr^{90} soil levels in 1958 and the Sr^{90} rabbit bone levels in 1958 and 1959 for the various sampling sites are listed in Table 7.22.

TABLE 7.22 1958 Sr^{90} Soil Levels and the 1958 and 1959 Jackrabbit Bone Levels at Various Sample Sites in Nevada and Utah

Approx. Miles from NTS	Sampling Area	Soil 1958 mc Sr^{90}/mi^2	Bone, pc Sr^{90}/gm Ca	
			1958	1959
0	Smoky Tower	9014	50.4	43.2
20	Area I, Nev.[a]	513	19.0	64.4
74	Moapa, Nev.	16	15.8	18.0
76	Delamar, Nev.	23	14.6	17.1
80	Warm Springs, Nev.	93	26.8	30.0
82	Glen Rox, Nev.	142	21.8	19.6
96	Overton, Nev.	21	15.5	13.9
132	Belmont, Nev.	32	23.8	28.0
135	St. George, Utah	46	19.6	25.3
136	Enterprise, Utah	41	13.7	19.3
232	Clear Lake, Utah	26	11.1	18.5
235	Antimony, Utah	29	16.2	17.3
240	Antimony-Otter Cr, Utah	44	15.0	15.4
270	Fremont, Utah	26	17.4	14.2
272	Reno-Sparks, Nev.	16	27.3	19.0
300	Fountain Green, Utah	38	13.3	22.4
356	Columbia, Utah	67	20.6	20.7
432	Vernal, Utah	14	11.9	12.9

[a] 13 miles north of Shot "U", Jangle Series (1951)

The data suggest (1) that the highest bone levels are frequently associated with the higher soil Sr^{90} levels, but the relationship between bone and soil Sr^{90} levels is not linear; and (2) that the bone levels remained essentially unchanged over the 1958-1959 period with the increase matched by the decreases.

The persistence of Sr^{90} in the soil environment was examined by additional studies conducted in the Smoky Stations VI and VII. The results are summarized in Table 7.23 and indicate that, within the limits of sampling accuracy, the Sr^{90} surface soil levels were unchanged over the 12 month period.

TABLE 7.23 Effect of Time on Sr^{90} Levels in Surface Soil (0 to 1 in.)

		Soil Sr^{90} Level of Samples mc/mi^2 at time of analysis (1959)	
Area	Miles	D + 3 days	D + 12 months
Station VI	99	127 ± 15	109 ± 31
Station VII	136	95 ± 15	114 ± 19

Samples of the soil profile were collected in Station VI area 3 days, 12 months, and 24 months after Shot Smoky. The analysis of these samples (Table 7.24), indicates that the Sr^{90} is primarily restricted to the surface inch with relatively small amounts in the second inch. This analysis is in agreement with similar studies of beta radioactivity and plutonium movements downward into soil over considerably longer periods of time in New Mexico soils contaminated by the Trinity Shot of 1945 (See Chapter 1).

TABLE 7.24 Effect of Time on Distribution of Sr^{90} Levels in Soil Profile, Station VI

		Soil Sr^{90} Level of Samples mc/mi^2 at time of analysis (1959)		
	Depth, inches	D + 3 days	D + 12 months	D + 24 months
Stake 1	0 - 1	104	89.5	128
	1 - 2	19.2	13.7	9.20
	2 - 3	Bkg[a]	Bkg	--
	3 - 4	Bkg	Bkg	--
Stake 13	0 - 1	112	154	106
	1 - 2	22.9	9.76	14.2
	2 - 3	15.9[b]	Bkg	--
	3 - 4	2.79[b]	Bkg	--
Stake 16	0 - 1	130	169	178
	1 - 2	19.5	29.8	3.07
	2 - 3	Bkg	5.58[b]	--
	3 - 4	Bkg	Bkg	--

[a] Bkg: Soil background.

[b] Probably sample contamination during collection.

These studies support the concept of a persistent Sr^{90} surface soil contamination of noncultivated areas in the environs of NTS.

Biological Availability: Differences in the half-lives of radionuclides in the precursor-chain of Sr^{89} and Sr^{90} suggest that the distribution of Sr^{89} should not be indicative necessarily of the distribution of Sr^{90}. The proportion of Sr^{89} to Sr^{90} in the bone ash of jackrabbits along the midline of a Teapot Series fallout pattern was found to be variable at different distances from ground zero (Chapter 1).

Subsequent studies were specifically related to the distribution of Sr^{90} in the environment and its accumulation by small native rodents. Because of the chronic nature of Sr^{90} contamination, the time sequence of accumulation has been emphasized.

A study area, Area I, was established in 1952 approximately 13 miles north of Shot "U" and had been ground zero in the two fallout patterns from the Jangle Series (November 1951). As indicated in Table 7.25, soil Sr^{90} levels in this area were increased by approximately an order of magnitude with this series.

TABLE 7.25 Sr^{90} Levels in Soil and Jackrabbit Bone from Area 1, 13 Miles North of Jangle "U" GZ

Contamination Event	Date of Collection	Soil Sr^{90} mc/mi^2	Bone pc Sr^{90}/gm Ca
Ranger, Jan/Feb 1951	Sept. 1951	23[a]	NC[b]
Buster/Jangle, Oct/Nov 1951	Nov. 1951	200[c]	NC
	Oct. 1952	NC	33 ± 13
Upshot/Knothole, Mar/June 1953	July 1953	438 ± 56	NC
	Apr. 1954	NC	26.3 ± 12.5
Teapot, Feb/May 1955	Apr. 1955	NC	9.4
	Oct. 1955	NC	11.8 ± 6.3
	Oct. 1956	570 ± 105	11.0 ± 0.85
Plumbbob, May/Oct 1957	June 1957	NC	24.1 ± 6.9
	Aug. 1957	NC	25.7 ± 12.4
	Aug. 1958	560 ± 73	19.0 ± 1.3
Hardtack II, Sept/Oct 1958	No Collection Made		
Kiwi-A July 1, 1959	Aug. 1959	386 ± 87	64.4 ± 33.8
	May 1960	564 ± 95	22.8 ± 12.7

[a] 0.9 mile northwest of area

[b] NC: no collection made.

[c] Estimated on basis of contaminated soil flats located preshot.

The availability of this fallout to plants in glasshouse studies was considerably greater than that observed for tower shot fallout. This material plus an increment of fallout from the Tumbler/Snapper Series resulted in a value of 33 pc Sr^{90}/gm Ca in the bone of rabbits collected in the fall of 1952. This was the highest value observed until 1959.

No apparent increase in Sr^{90} of bone was recorded following the Upshot/Knothole Series in the spring of 1953 nor following an apparent 30% increase in the Sr^{90} of the soil during the Teapot Series of 1955. An approximate doubling of the previous year's bone level was detected due to this series (Plumbbob), although soil levels apparently were not increased. An increase was also observed immediately following the first nuclear propulsion experiment (Kiwi A) in 1959.

Shot Smoky increased the Sr^{90} contamination level of soil at Station VI by an estimated 65% to approximately 100 mc/mi^2. As stated earlier in this chapter, kangaroo rats and jackrabbits were collected 3, 5, 9, 13, and 20 days after fallout to determine the early rates of fission product accumulation (Table 7.26). Kangaroo rats and jackrabbits showed an early response to the additional Sr^{90} increment, at least as early as the second collection (D + 5 days). A rapid equilibrium was also demonstrated between the animals and the environment since maxima were generally reached well before the 20 day sampling period was completed. Similar rapid response and equilibration with the environment were observed with respect to the shorter lived, bone seeking fission products, Sr^{89} and Ba^{140}, in rabbit bone.

TABLE 7.26 Sr^{90} Levels in Bone of Kangaroo Rat and Jackrabbit, Station VI

Date of Collection	Sr^{90} in Bone pc Sr^{90}/gm Ca	
	Kangaroo Rat	Jackrabbit
Oct. 12/55	--	20.6
Aug. 31, 1957 Contaminating Event:	Shot Smoky	
Sept. 3/57	5.34	20.7 ± 9.93
Sept. 5/57	6.62	22.7
Sept. 9/57	6.43	26.8 ±13.6
Sept. 13/57	9.64	25.0 ± 6.98
Sept. 20/57	8.69	--
July 3/58	8.33	--
July 7/58	8.48	19.4 ± 5.27
Aug. 12/59	--	33.4 ±12.7
May 1960	--	19.3 ± 7.04
May 1961	--	10.0 ± 6.32

Subsequent sampling of kangaroo rats showed that the maximum levels of Sr^{90} bone contamination reached during the 20 day initial sampling period tended to be maintained 1 year later. Jackrabbit bone levels reflected an increase in 1959, a return to the 1958 level in 1960, and an abrupt drop in 1961.

The relatively poor correlation between the Sr^{90} levels in soil and bone suggests that some fraction, ratherthan the total, of the Sr^{90} fallout was of primary significance with respect to biological uptake. For example, when 1958 soil samples collected along the Smoky midline were leached with 6 N HCl, the correlation between the Sr^{90} soil levels so obtained and the corresponding bone levels was much improved (Table 7.27).

TABLE 7.27 Comparison of Bone Sr^{90} Levels to Soil Sr^{90} Levels[(a)]

Location	Miles from NTS	Sr^{90} in Jackrabbit bone, pc/gm Ca	Total soil Sr^{90}(b)	HCl soluble Sr^{90}(c)	Percent soluble Sr^{90}
			mc/mi^2		
Smoky Area	1	50.4	9014	980	10.9
Nye 1, Nev.	12	23.2	933	58	6.2
Glen Rox, Nev.	80	21.5	142	18	13.0
Enterprise, Utah	140	13.8	41	27	66.7
Panguitch, Utah	205	12.9	32	16	50.3
Columbia, Utah	350	20.9	67	48	71.8

[a] Determined by fusion and 6 N HCl extraction (1958 sample collection)

[b] Determined by sodium carbonate fusion method of analysis

[c] Determined by extracting with 6 N HCl

It is noteworthy that the Sr^{90} which is soluble in HCl represents an increasing percentage of the total Sr^{90} as distance from ground zero is increased, which agrees well with the increasing percentage contribution of less than 44 micron fallout particles at greater distances from ground zero. In addition to enhanced solubility properties over larger materials, such particles are somewhat enriched in Sr^{90} content apparently due to a rare gas precursor which limits the incorporation of this particular nuclide at the earlier time of formation of larger particles. Consequently, it seems feasible to consider the more soluble and ubiquitous small fallout particles as the major source of Sr^{90} to the native animals in the fallout pattern.

Despite what appears to be a rather constant Sr^{90} soil environment, sharp drops in the jackrabbit Sr^{90} bone levels were observed in Area 1 in 1955 and in Station VI in 1961. If the bone levels of jackrabbits collected in the latter area in 1958 and 1961 are plotted as a function of body weight, which may be used as a rough indication of animal age, the values are distributed as illustrated in Figure 7.10. In 1958, one year after the Shot

Smoky contamination, 41 of 43 animals had Sr^{90} bone levels in excess of 10 pc Sr^{90}/gm Ca regardless of weight (or age). In contrast, in 1961, 39 of 53 animals had bone levels of less than 10 pc Sr^{90}/gm Ca. The higher levels were restricted to the heavier, or older, animals.

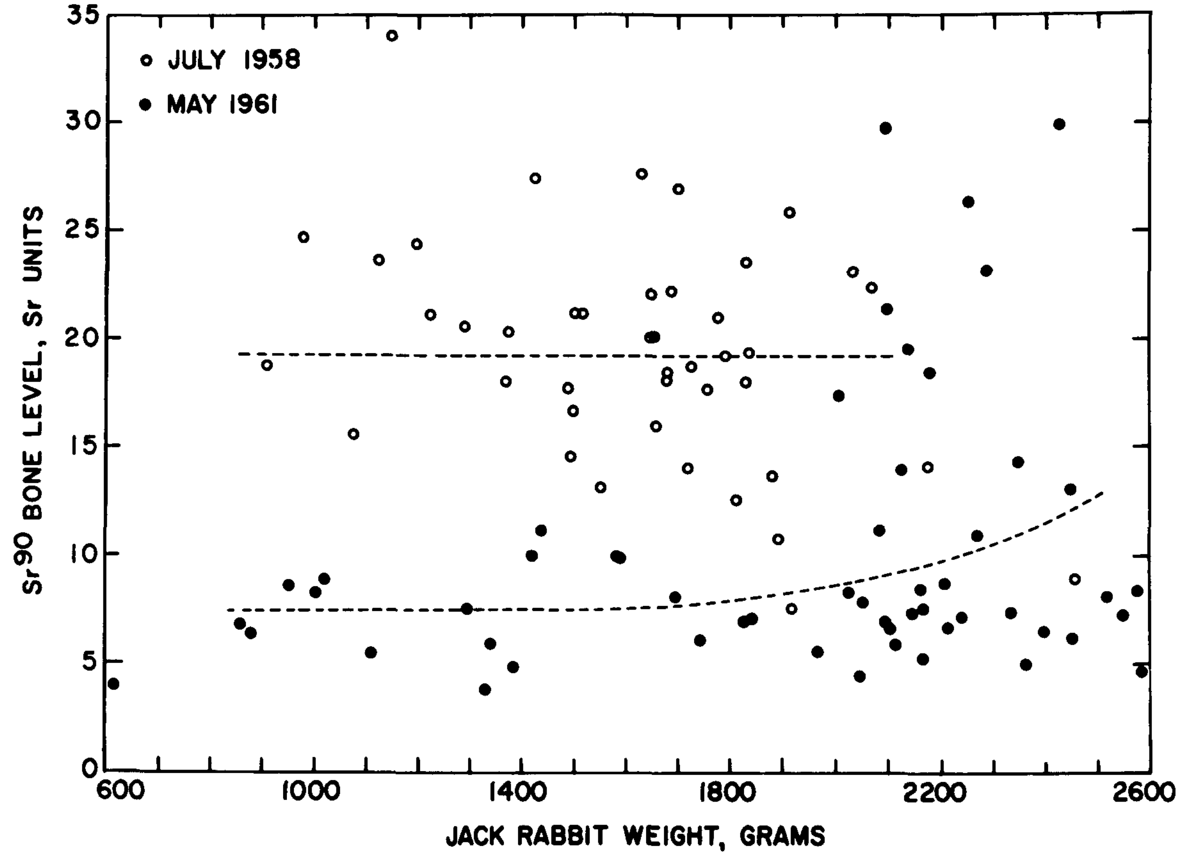

Figure 7.10 Comparison of Bone Sr^{90} Levels in Jackrabbits Collected Near Station VI in 1958 and 1961.

The fact that older animals of the 1961 population included individuals having both low and high Sr^{90} levels, coupled with an estimated life span of at least 2.7 years for the oldest jackrabbits in this area (References 5 and 6), strongly implies that the higher levels of Sr^{90} are associated with animals which were living early in the sequence of contamination--i.e., the Plumbbob fallout--rather than with animals which were born later and merely lived in a contaminated environment.

There are a number of possible explanations for a lower Sr^{90} bone level of animals born subsequent to contaminating events. For example, plant foliage serving as food has a higher contamination level immediately after fallout. It was first shown during the Teapot Series (1955) that vegetation tends to be a selective fallout collector for fallout particles which range predominantly from the less than 1 to 14 microns in diameter in the great number of samples investigated.

Data presented in Figuries 6.8 and 6.9 show that, by comparing the decay rate of fallout in the environment to the beta radioactivity level of serially sampled plant leaves, the entrapped particles were persistent for the sampling period extending from 3 to 20 days after fallout. However, the contamination of new growth appears to be due to a very few particles of redistributed fallout. Gross beta analysis and autoradiograms of Station VI plant material collected in 1961 did not reveal the presence of particulate contamination.

It should also be noted that native vegetation in Nevada has not been shown to accumulate fallout-derived fission products via the root system; autoradiograms of plant materials collected during or immediately after test series have shown only point-surface contamination indicative of particulates rather than the diffuse distribution pattern indicative of metabolized radioisotopes.

Several observations among the presented data lend support to the concept that only a fraction of the total Sr^{90} in fallout debris deposited in environs of NTS is available for metabolism by indigenous animals. In Area I (Table 7.25) the June, 1957, increase of Sr^{90} in bone was approximately twice the 1956 level and occurred within a few days after the first detonation of the Plumbbob Series. In July 1959, a similar abrupt increase of Sr^{90} levels in bone in Area I immediately after the Kiwi-A experiment in the adjacent Jackass Flats.

In Station VI (Table 7.26) the maxima in bone levels which were reached rapidly during the 20 day serial sampling period, likewise suggest that a fraction of the total deposited Sr^{90} is biologically available. Under such circumstances, inhalation as a mechanism might be suspected; however, with domestic rabbits, inhalation was shown to be relatively unimportant as a method of particulate contamination during the Teapot Series of 1955 (Chapter 1).

The relative importance of the various pathways by which fallout-derived Sr^{90} may enter the animal is not readily apparent. However, it is apparent from the occurrence of reductions in the Sr^{90} bone levels of the jackrabbit population several years after contaminating events, that the biological availability of Sr^{90} is much greater at some early time after fallout. It is also quite likely that mechanisms for the reduction of potentially available Sr^{90} exist in the environment, regardless of apparently persistent Sr^{90} soil levels.

7.4 SUMMARY

1. The data presented are representative of the relative fission product accumulations in adult animal population of the species studied within an overall factor of two.

2. Comparison of the biotic data from five different detonations shows a marked similarity in the pattern of mixed fission product accumulation (total beta activity) in animal tissues. The similarity is apparent when the data are related to the time at which fallout occurred. Total activity in tissues tended to decrease as the fallout time-of-arrival increased.

3. The rate at which the total beta activity in tissues decreased with increasing time of fallout was slightly greater for the balloon supported Shot Priscilla than for four tower supported detonations and correlated with differences in the amount of the less than 44 micron fallout material that was deposited.

4. For comparable locations within the two fallout patterns (Priscilla and Smoky), the amount and kinds of radionuclides present in bone samples were similar despite differences of orders of magnitude in the amount of fallout deposited by the two shots. This similarity can be accounted for by the relatively higher solubility of the Priscilla fallout material.

5. Biological 'hot spots' were identified with Boltzmann (78 miles from ground zero), Diablo (60 miles from ground zero), and Shasta (172 miles from ground zero) fallout patterns. The degree of biological accumulation in the Boltzmann and Diablo hot spots reflected the heavy deposition of fallout, particularly of the less than 44 micron fraction, in these areas. However, high values occurred in animal tissues sampled from a Shasta location even though dose rates obtained by ground and air monitoring failed to reveal correspondingly high levels of deposited radioactive debris in that area. Other animal tissues sampled from the Shasta radiological hot spot did not show high fission product concentrations.

6. Apart from the exceptions shown by comparison of the tower supported Shot Smoky and balloon supported Shot Priscilla, the pattern of biological accumulation of beta activity appears to be similar for the detonations studied during the Plumbbob, Teapot, and Upshot/Knothole Test Series.

7. Jackrabbit bone levels of Sr^{90} from animals in Station VI Area were about the same in 1958 as in 1957. There was an increase reflected in 1959, followed by a decrease to the 1957-58 levels in 1960, and an abrupt drop in 1961, i.e., from 25 to 10 pc Sr^{90}/gm Ca. This occurred despite the apparent constant level of Sr^{90} soil environment.

8. Data suggest that the higher levels of Sr^{90} in the indigenous animals are associated with animals which were living in the early sequence of contamination, i.e., during and immediately after fallout, rather than with animals that were born later and merely lived in the contaminated environment.

REFERENCES

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3. D. H. Peirson; "The Interpretation of Gamma Ray Scintillation Spectra from Fission Product Mixtures"; Report AERE EL/R 2598; Atomic Energy Establishment; Harwell, Berkshire, England; Unclassified.

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5. Hayden, P. and H. French: Private Communication, 1961.

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CHAPTER 8

FALLOUT IN AGRICULTURAL SYSTEMS

Fallout injected into the agricultural activities conducted in the region surrounding the Nevada Test Site was evaluated for its significance to food production. Accumulations of radionuclides in soils of the region from earlier test series were determined. The distribution of fallout debris from Operation Plumbbob among crops and underlying soils was determined. Its subsequent redistribution by natural processes and those incident to the cultural activities required for food production were defined.

The levels of radioactive contamination associated with crops used by the production of milk were assessed and related to the Sr^{90} and Cs^{137} content of the milk produced. Fallout solubility was compared to biological availability. The significance of biological availability of debris from Shots Priscilla and Smoky was defined to better relate such factors as fallout deposition and the physical and chemical properties of the fallout material, with the agricultural cycle wherein man's food originates.

8.1 PROCEDURES

This study was dependent upon fallout patterns crossing operating farms, especially dairy farms. The level of radioactive contamination determined the duration of the study. Two mr/hr at H + 12 hours was estimated to be the minimum acceptable dose rate to accomplish the objectives of the project. Such a dose rate would afford the opportunity to determine the biological availability of Sr^{90} and Cs^{137} from close-in fallout, as measured by concentrations of these radionuclides in milk from dairy cattle maintained in contaminated environments. When feasible, farms were selected for study near Project 37.1 study areas or Project 37.2a stations.

Selected areas were sampled pre-Plumbbob in order to establish background reference values. Each area was located within 3 miles of a U. S. Public Health Service surveillance station. An estimate of pre-Plumbbob fallout contamination, expressed as infinite gamma dose is summarized in Table 8.1. Also, five of these areas were farms that had been documented by the AEP/UCLA group following the Teapot Series (1955) because of their proximity to the midlines of the respective fallout patterns.

Dairies were operating on seven of the farms selected. Samples of soil, forage crops, hay, dairy suppliment feeds, cattle feces, and milk were collected from these dairies.

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* The experimental work, interpretation, and writing in this Chapter were done by Dr. H. A. Hawthorne. This work served as a basis for Dr. Hawthorne's continuing study of radionuclides in agricultural environments being done at the Laboratory of Nuclear Medicine and Radiation Biology, UCLA.

Soil samples were collected from the other selected areas. All areas were resampled after Operation Plumbbob in order to establish a comparative set of data.

TABLE 8.1 Infinite Gamma Dose at Selected Locations in the NTS Environs

Estimated doses and geographic locations obtained from Reference 1. NS, not significant.

Monitoring Location	Infinite Dose. R		
	Pre-Plumbbob	Plumbbob	Total
Barstow, Calif.	0.01	NS	0.01
Bishop, Calif.	NS	0.06	0.06
Alamo, Nev.	1.30	0.04	1.34
Caliente, Nev.	0.70	0.01	0.71
Eureka, Nev.	0.20	0.60	0.80
Lund, Nev.	0.80	0.44	1.24
Mesquite, Nev.	1.80	0.24	2.04
Overton, Nev.	0.35	0.08	0.43
Pahrump, Nev.	0.20	NS	0.20
Tempiute, Nev.	4.00	1.90	5.90
Beaver, Utah	0.25	NS	0.25
Beryl Jct., Utah	1.00	0.05	1.05
Cedar City, Utah	0.40	0.24	0.64
Milford, Utah	0.10	NS	0.10
Panguitch, Utah	0.20	0.50	0.70
St. George, Utah	3.00	0.70	3.70
Veyo, Utah	2.00	0.82	2.82

Agricultural areas sampled after fallout contamination from various Plumbbob shots are identified in Table 8.2. Farms within the fallout patterns from Shots Priscilla and Smoky were selected for comprehensive studies. Available data from Projects 37.1, 37.2 and 37.2a on these fallout patterns permitted a more complete documentation of the amount of deposited fallout material and its characteristics then heretofore available. All agricultural areas were documented and the samples assayed according to the detailed procedures described in Appendix A, Section A.2.6.

8.2 RESULTS AND DISCUSSION

8.2.1 Accumulation of Cs^{137} and Sr^{90} in Soil from Farms in the NTS Environs

Data presented in Table 8.3 show the pre- and post- Plumbbob concentration of Cs^{137} in soil collected from nine farms and three grazing areas (virgin soils) in the NTS environs. The amount of Cs^{137} in soil collected from the plow layer, i.e., the top 6 inches, of cultivated fields on these farms was apparently dependent upon the number of fallout patterns that had crossed the area. In samples collected pre-Plumbbob, Cs^{137} values ranged from 18.5 to 82.5 mc/mi^2. Post-Plumbbob, the Cs^{137} values in soil samples from six farms sampled pre-Plumbbob ranged from 38.8 to 82.7 mc/mi^2 with no change in three locations.

TABLE 8.2 Geographical and Radiological Descriptions of Collection Locations

Radiological data supplied by Project 37.2. Fallout patterns shown in Chapter 2 figures. Dose rate normalized to T-1B equivalent dose. (A), split midline. E, time of fallout arrival extrapolated. I, mr/hr from isopleths. Jct, junction. Hwy, highway. Rd, road.

Collection Location	Shot fallout pattern	Shot date 1957	Miles from GZ	Miles from midline	Fallout time, H + hour	Dose rate at H + 12 hour, mr/hr
Farms						
Bishop, Calif. 0.5 mi W Jct Hwy 6 and 395, on Hwy 395	Kepler Wheeler	7/24 9/2	128 128	60 SW 20 N	12.0 E	2 I
Barstow, Calif. 1.4 mi E, 0.6 mi S Jct Hwy 91 and 466	Coulomb B	9/16	--	--	--	<0.1 I
Alamo, Nev. 1.2 mi S of high school	Wilson Priscilla Diablo	6/18 6/24 7/15	52 58 55	10 S 22 N 40 S	14.0 E 6.2 E 6.2 E	0.75 0.75 I 0.8 I
Caliente, Nev. 3.3 mi S Jct Hwy 93 and Elgin Rd, on Elgin Rd	--	--	--	--	--	--
Lund, Nev. 0.8 mi S of high school,0.6 mi W, 0.2 mi S	Hood Diablo Owens	7/5 7/15 7/25	130 130 130	28 N 15 E 21 E	7.4 E 12.3 E 6.0 E	0.3 6 0.4
Lund, Nev. 0.8 mi S of high school,0.6 mi W, 0.2 mi S	Shasta Doppler Charleston	8/18 8/23 9/28	130 130 130	65 E 4 E(A) 13 E(A) 39 E	10.0 E 10.8 E	1.0 >1.0 <0.3
Mesquite, Nev. 2.6 mi S of post office on Hwy 91, 0.5 mi SE	Smoky La Place	8/31 9/8	115 115	17 S 0	7.0 13.0E	1.3
Overton, Nev. 0.1 mi E city limit on Hwy 12	Smoky La Place	8/31 9/8	95 95	22 S 16 S	8.5 E 11.3 E	1.2
Pahrump, Nev. 5.6 mi S Jct Hwy 52 and 16, 0.5 mi E Hwy 16	--	--	--	--	--	--
Antimony, Utah 1.4 mi N of grammar school, 0.4 mi E of Hwy 62	Smoky	8/31	233	0 (A)	14.2E	7
Beaver, Utah 1.1 mi W Jct Center and Main Street	Smoky	8/31	205	26 N	12.0 E	<0.5 I
Cedar City, Utah on College Southern Utah campus	Priscilla Smoky	6/24 8/31	170 170	7 N 19 N	12.0 E 5.6	0.5 4.5
Beryl Jct, Utah 0.9 mi NWof Jct Hwy 18 and 56, 0.5 mi S Hwy 56	Priscilla Smoky	6/24 8/31	146 146	24 N 21 N	12.0 E 4.5 E	0.5 I 0.5
Fremont, Utah 1.3 mi S city limit on Hwy 72	Smoky	8/31	259	3.5 S(A)	16.5 E	4
Milford, Utah 3.9 mi S Jct Hwy 129 and railroad, 0.8 mi W	Smoky	8/31	187	50 N	11.0 E	<0.5
Panguitch, Utah 0.3 mi N Courthouse, 0.6 mi W Hwy 89	Smoky	8/31	205	0	11.8	14
St. George, Utah 0.4 mi E Nat'l. Guard Armory, 0.6 mi S on Hwy 64	Priscilla Smoky	6/24 8/31	139 138	18 S 7.5 S	9.5 7.2	0.5 I 10
Veyo, Utah 0.4 mi E Jct Hwy 18 and Gunlock Rd, 0.6 mi N	Priscilla Smoky	6/24 8/31	133 132	0.6 N 9.5 N	7.1 4.7	6 5
Virgin Areas						
Delamar, Nev 20 mi W Caliente on Hwy 93, 14.4 mi S	Wilson	6/18	80	5 NW	13 E	0.8 I
Eureka, Nev 2.0 mi W of post office on Hwy 50	Owens Shasta	7/25 8/18	172 172	24 W 2 E	8 E 13 E	0.9 I 4 I
Tempiute, Nev. 1.6 mi W of post office	Wilson Hood Diablo Doppler	6/18 7/5 7/15 6/23	42 42 46 46	15 NW 6 E 0 4 W	10 E 2.5 E 5.5 E 3.5 E	0.7 I 0.7 I 50 I 0.1 I

TABLE 8.3 Cs^{137} in Agricultural Soils of the NTS Region, Before or After Operation Plumbbob

Soil cores were of 0-6 inch depth except 0-2 inches at Eureka and Tempiute, Nevada, 0-4 inches deep at Lund, Nevada, in May. See Table 8.2 for collection locations. Cs^{137} analysis by Dr. P. F. Gustafson, USAEC Argonne National Laboratory. NA, no analysis made.

Collection Location	Core Samples April-May	Core Samples October-November	Surface Soil April-May	Surface Soil October-November
	mc/mi^2		mc/mi^2	
Farm Soils				
Alamo, Nev.	53.7	82.7	11.9	11.7
Caliente, Nev.	18.5	38.8	NA	NA
Lund, Nev.	64.2	58.5	18.8	24.9
Mesquite, Nev.	60.3	60.8	NA	NA
Beaver, Utah	82.5	70.6	NA	NA
Beryl Jct., Utah	NA	NA	12.7	17.5
Cedar City, Utah	37.1	57.1	NA	NA
Milford, Utah	NA	NA	27.0	26.0
St. George, Utah	34.2	73.4	21.2	21.1
Virgin Soils				
Delamar, Nev.	NA	NA	14.2	NA
Eureka, Nev.	12.4	12.2	NA	NA
Tempiute, Nev.	30.7	67.8	NA	NA

The amount of Cs^{137} in pre-Plumbbob surface soil samples (0 to 1 inch depth) from five of the above nine farms ranged from 11.9 to 27.0 mc/mi^2. Post-Plumbbob, the Cs^{137} values in surface soil from three farms ranged from 11.7 to 26.0 mc/mi^2 with no change in two locations.

There is no apparent correlation between the amount of Cs^{137} in the plow layer and the Cs^{137} in the surface layer or the infinite gamma dose (Table 8.1). Several factors that may influence this observation will be discussed in the following Sections.

A wide range of Sr^{90} concentration occurred in the soil cores collected within 205 miles of the Nevada Test Site in the fall of 1957; therefore, an average Sr^{90} value for this region was inappropriate (Figure 8.1). The acid leaching procedure recommended for worldwide surveys of soil Sr^{90} was used to obtain the acid-soluble Sr^{90} levels shown in Figure 8.1. These ranged from 2.0 to 42.3 mc Sr^{90}/mi^2.

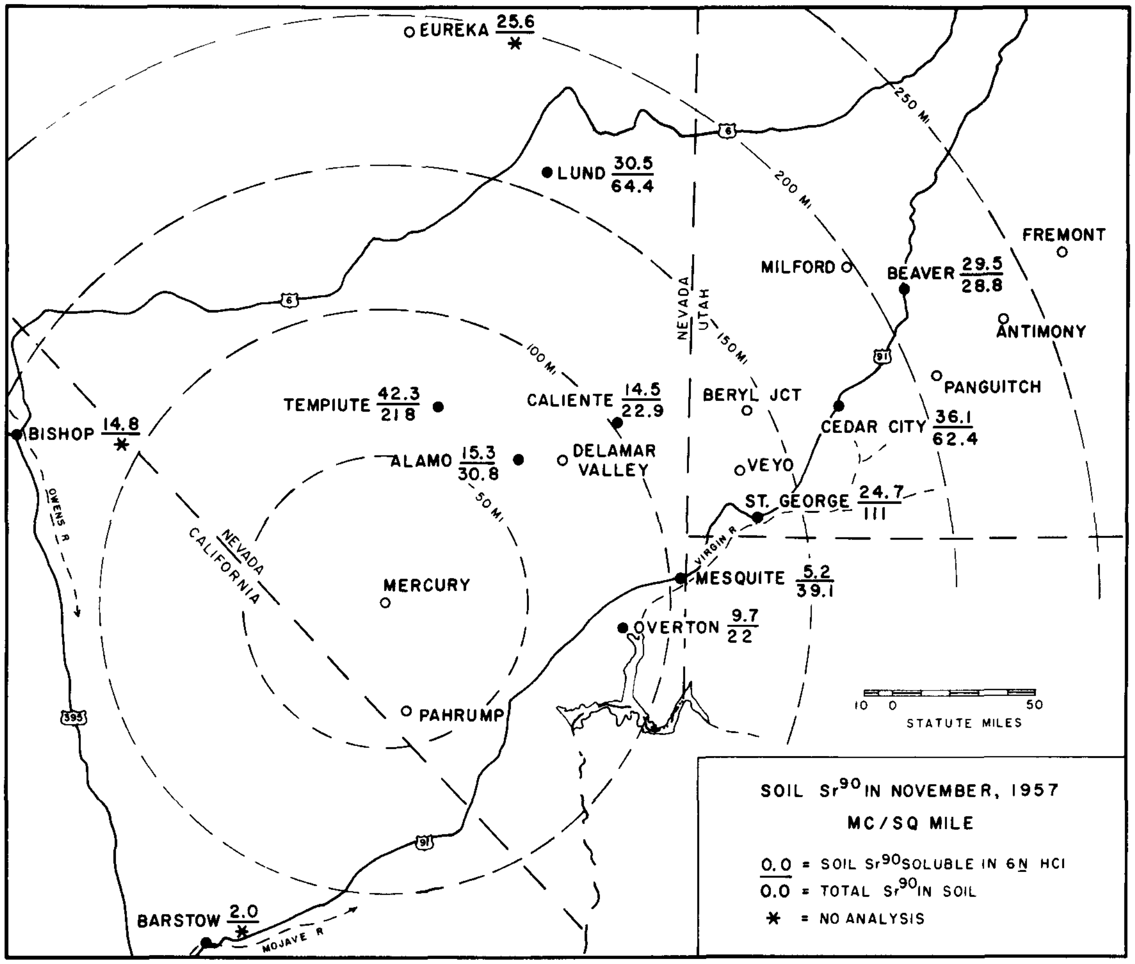

Figure 8.1 Acid-Soluble and Total Sr^{90} in Soils Within 205 Miles of the Nevada Test Site, November 1957.

For comparative purposes, total Sr^{90} was measured in a duplicate set of soil cores following a carbonate fusion; Sr^{90} values obtained by this procedure were generally much higher than those obtained by leaching the soils with 6 N HCl. Consequently, the carbonate fusion method was used for determining the total Sr^{90} in soils during this study. The data are presented in Figure 8.1

8.2.2 Chemical Properties of NTS Fallout in Soil

The 6 N HCl solubility of Sr^{90} in soil varied from 13 to 100 percent of the amount of Sr^{90} found by the carbonate fusion method (Table 8.4). The solubility of Sr^{90} in fallout debris is considered to be an important factor in determining the biological availability of the Sr^{90} to plants, to domestic animals, and to man.

TABLE 8.4 Soil Sr^{90}, Acid-Soluble Sr^{90}, and Infinite Gamma Dose at Various Distances from GZ

Soil samples are 0 to 6 inches deep. Collection locations are defined in Table 8.2. Infinite dose are taken from Table 8.1. Extractions with 6 N HCl and Sr^{90} analyses by USAEC Health and Safety Laboratory, New York Operations Office.

Collection Location	Infinite Dose, roentgens	Distance from GZ, miles	Total Sr^{90}, mc/mi^2	Sr^{90} Soluble in 6 N HCl, pct
Tempiute, Nev.	5.9	45	218	19
St. George, Utah	3.7	135	111	22
Mesquite, Nev.	2.0	115	39.1	13
Alamo, Nev.	1.3	55	30.8	50
Lund, Nev.	1.2	130	64.4	47
Caliente, Nev.	0.7	95	22.9	63
Cedar City, Utah	0.6	170	62.4	58
Overton, Nev.	0.4	95	22	44
Beaver, Utah	0.3	205	28.8	102

Data related to the solubility of Sr^{90}, shown in Figure 8.1, Tables 8.1 and 8.2, are summarized in Table 8.4. Linear relationships were not indicated for the variables tabulated. There was an inverse relationship between fallout gamma dose (in roentgens) and the acid solubility of Sr^{90} in that the least-soluble fallout material was at locations at which the radiation dose was greatest and that the most-soluble Sr^{90} was at the location with the lowest fallout intensity. At locations having fallout of intermediate acid solubility, there was little correlation between solubility and either the total Sr^{90} deposited or the fallout intensity.

Soil properties were not significant in affecting the acid-solubility of Sr^{90}. Laboratory studies indicate the recovery of Sr^{85} from "spiked" samples ranged from 87 to 99 percent with 6 N HCl; and, with 1 N ammonium acetate (NH_4OAc), the recovery was between 77 and 90 percent (Table 8.5).

TABLE 8.5 Soil Strontium Solubility in Hydrochloric Acid and Ammonium Acetate

Soil cores are 0 to 6 inches deep from collection locations defined in Table 8.2. Sr^{90} recovery is taken from Figure 8.1. SD, standard deviation.

Collection Location	Pct Sr^{85} Recovered		Pct Soil Sr^{90} Recovered in
	6 N NCl	1 N NH_4OAc	6 N HCl
Alamo, Nev.	99.5	90.5	50
Caliente, Nev.	95.6	79.3	63
Lund, Nev.	87.3	76.7	47
Mesquite, Nev.	92.8	87.1	13
Beaver, Utah	95.0	78.4	102
Cedar City, Utah	94.5	87.4	58
St. George, Utah	91.1	78.6	22
Mean ± SD	93.5 ± 5.1	82.3 ± 5.8	50.7 ± 29.1

Samples from Mesquite and Lund were selected to represent the least solubility of soil Sr^{90} and an intermediate solubility. To simulate field irrigation practices in the laboratory these soils were wet and dried through twenty cycles to simulate irrigation treatments in the field. Repeated wetting and drying cycles had little effect on Sr^{85} recovery. The percent recovery of Sr^{85} in HCl and ammonium acetate respectively, were Lund, 84 and 94 and Mesquite, 81 and 83. The results of the experiment indicated that soil characteristics *per se* did not cause significant differences in acid-solubility of Sr^{90} fallout from the soil cores.

The relatively low solubility of Sr^{90} in cumulative fallout deposited near NTS is largely an indication of the larger proportion of low solubility debris deposited "close in". Several of the sampling sites were near midlines of fallout patterns from tower detonations. Such detonations have predominated at NTS, and many of the fireballs have intersected the ground. Most of the radioactivity in the debris has been found in relatively insoluble, large particles (Section 1.2.3).

Theoretically it should be possible to determine the Cs^{137} content of a soil sample by gamma spectrometry and to multiply this by a fixed Cs^{137}-to-Sr^{90} ratio to obtain the Sr^{90} present in the sample. Confirmation of the validity of this technique was sought.

It was found that using this theoretical radioactivity ratio to predict Sr^{90} in soils with high Sr^{90} levels in the vicinity of NTS could underestimate the Sr^{90} by a factor of nearly 6. The Cs^{137}-to-Sr^{90} ratio in soil from eight locations (Tables 8.3, 8.4) showed significant deviations from the theoretical 1.76 ratio (Figure 8.2). The Cs^{137}-to-Sr^{90} ratio was high at locations with little fallout and progressively decreased as the soil Sr^{90} increased. The correlation coefficient of -0.95 (significant at the 1 percent level) indicated that the empirical least squares relationship between low Cs^{137}-to-Sr^{90} ratios and high soil Sr^{90} levels was consistent.

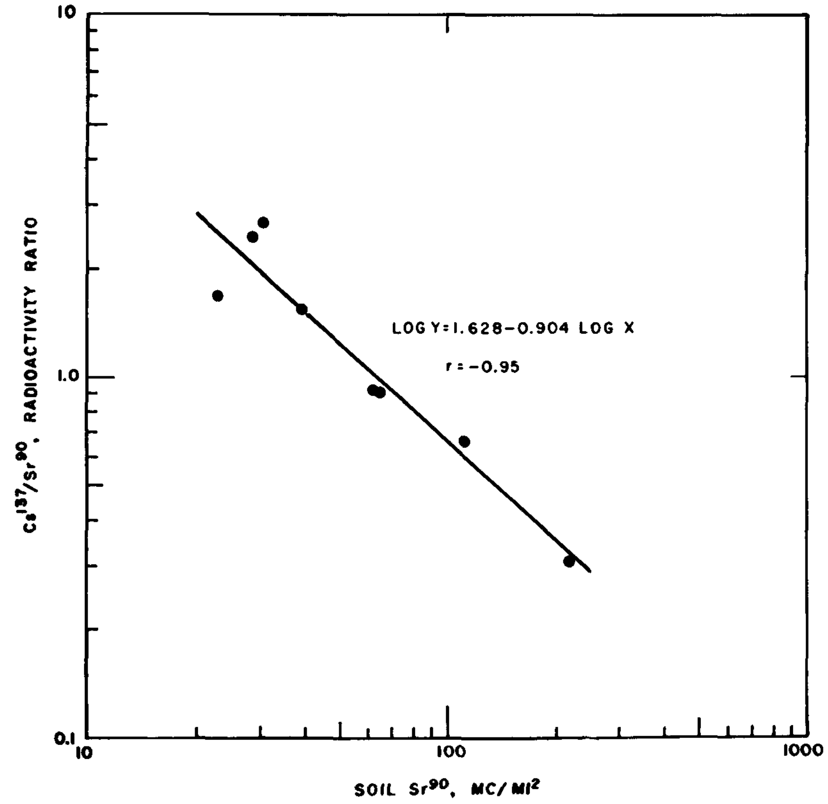

Figure 8.2 Relationship Between Cs^{137}-to-Sr^{90} Radioactivity Ratio and Total Sr^{90} in Soil Samples, November 1957.

The cause of low activity ratios in NTS soils, contaminated by tower supported detonations, was the low activity ratios in particles from those detonations. The soil at locations with the heaviest Sr^{90} deposits was known to be contaminated by fallout from devices detonated on towers. The activity ratios of fallout particles from the tower supported Smoky detonation are shown in Table 8.6. The ratios were 10 to 40 percent of the theoretical ratio and show that the particles were Cs^{137}-deficient relative to Sr^{90} There was a consistent decrease in the activity ratio with increasing particle size at deposition times from 1 to 6.5 hours.

TABLE 8.6 Cs^{137}-to-Sr^{90} Radioactivity Ratios of Smoky Fallout Particles at Time of Deposition

Particle Diameters, Microns	Hour of Fallout Arrival			
	H + 1.15	H + 4.5	H + 5.6	H + 6.5
	Cs^{137}/Sr^{90} Ratio			
0-44	0.77	0.47	0.36	0.35
44-88	0.37	0.36	0.42	0.30
149-250	0.20	NA[a]	NA	0.27

[a] NA, no analyses made

8.2.3 Strontium^{90} and Cesium^{137} in Milk from Farms in the NTS Region

Milk derived from feeds contaminated by Shot Smoky showed the greatest variation in strontium units (pc Sr^{90}/gm Ca) of milk from the feed production period 1956 to 1959. The decreased strontium unit variation in 1958 milk and its further reduction in 1959 milk were interpreted as indicating that contamination from Operation Plumbbob was progressively decreasing in susceptibility to redistribution (Figure 8. 3).

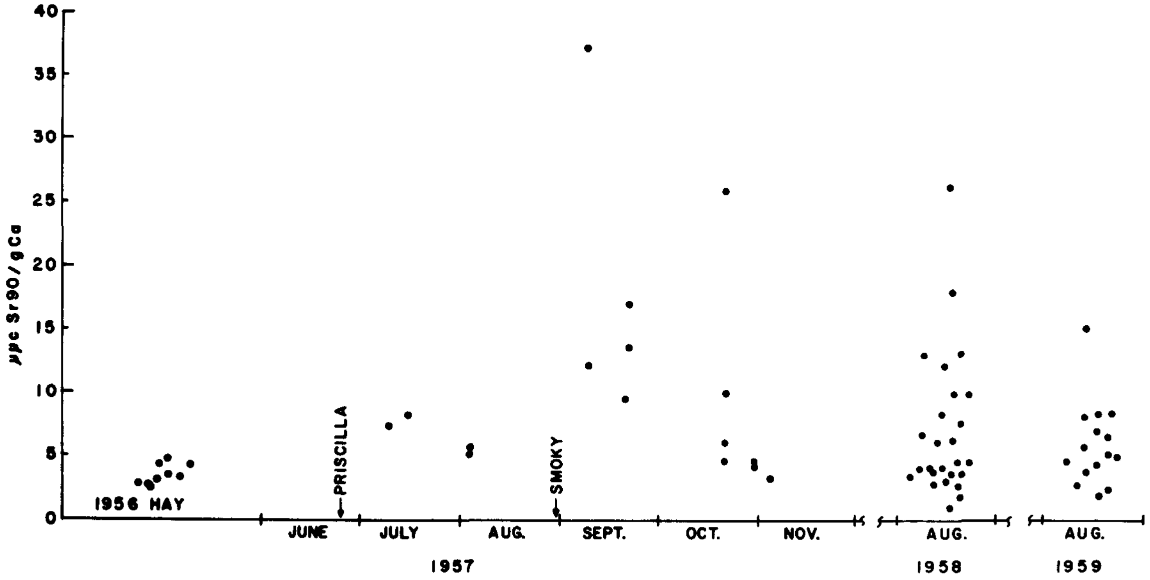

Figure 8. 3 Strontium Units in Milk as a Function of Time of Feed Production, 1956 to 1959.

The milk for Sr^{90} data in Figure 8. 3 came from dairies bounded on the northwest by Beckworth, California proceeding eastward through Reno and Austin, Nevada and Oak City, Utah to Kemmerer and Rock Springs, Wyoming on the northeast; southward through Artesia, Fremont, Panguitch and Hurricane, Utah to Overton and Pahrump, Nevada and back to Bishop, California on the southwest.

In the 1958 and 1959 surveys, the milk came from dairies located in fallout patterns from Operation Plumbbob. More than half the samples came from dairies in either the Boltzmann or the Smoky fallout patterns (Chapter 2, Figures 2. 1 and 2. 7 a, b, respectively). The Boltzmann fallout pattern was represented by milk from six dairies in the 1958 survey and from four dairies in the 1959 survey. The Smoky pattern was represented by milk from fifteen dairies in 1958 and from eight dairies in 1959. The ranges in strontium units of the milk from dairies in both of these fallout patterns overlapped, and the means of these units were sufficiently close to the general mean for all of the milk in each of these 2 years so that there was no significant difference in strontium units.

Milk from cows which were fed 1956 hay had the lowest mean strontium units and the smallest standard deviation of milk in the 4 year period (Figure 8. 3). The highest mean strontium units and the greatest standard deviation was in milk produced from feeds contaminated by the Smoky fallout pattern midline during Operation Plumbbob. The strontium units in milk from the 1958 and 1959 surveys showed progressively lower mean strontium units and decreasing standard deviations. In the 1958 survey, milk from dairies located near Shot Boltzmann and Smoky fallout pattern midlines had the higher strontium units. At a given distance from ground zero in the 1959 survey, milk with the highest strontium units was not necessarily from a dairy near the location of the maximum Plumbbob gamma dose rate.

The mean values and standard deviations for the concentration of Sr^{90} and Cs^{137} in milk produced by cattle maintained on feeds produced in the years 1956 through 1959, showed the same trends described for the strontium units. Our interpretation is that fallout particles from Operation Plumbbob were becoming increasingly difficult to remove from their original positions by redistribution processes occurring in the NTS environs (Figure 8. 4).

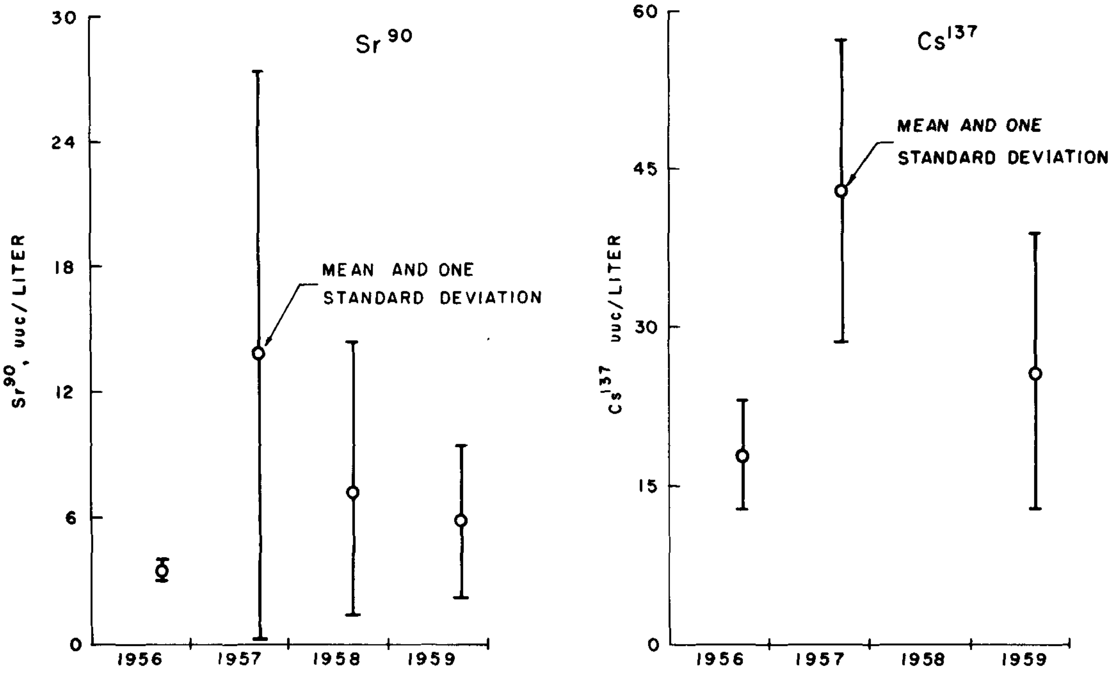

Figure 8. 4 Variation in Concentrations of Sr^{90} and Cs^{137} in Milk Produced from Feeds Grown, 1956 to 1959.

The Cs^{137} and Sr^{90} in milk approached equivalent concentrations during the highest Sr^{90} concentrations in the samples taken in 1957 and 1959 (Figure 8.5). The correlation coefficients of 0. 78 and 0. 70 (significant at the 1 percent level) for Plumbbob and 1959 milk, respectively, show clearly that the relative increases in Cs^{137} and Sr^{90} were not linearly related. The "best-fitting equation" relating concentration of Cs^{137} to those of Sr^{90} in the same milk samples was derived by "least squares" methods.

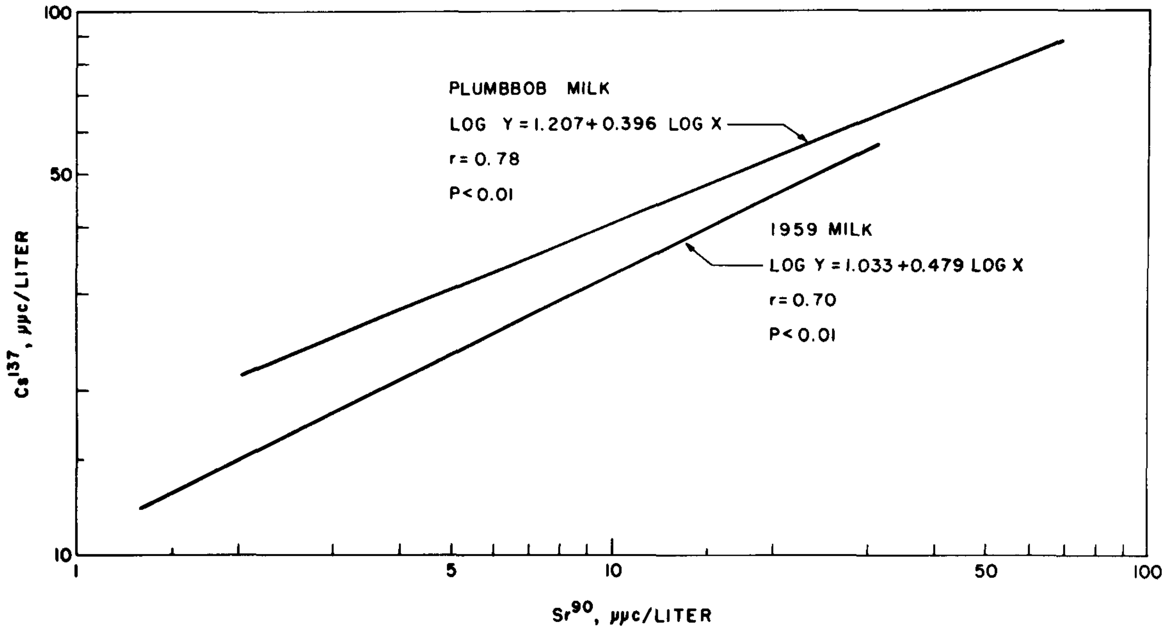

Figure 8.5 Relationship Between Concentrations of Cs^{137} and Sr^{90} of Milk Produced Either from 1959 Feeds or After Shots Priscilla and Smoky.

The "best fitting equations", relating the concentrations of Cs^{137} to Sr^{90} in milk produced from 1956 feeds or from 1957 feeds that were not contaminated by Plumbbob fallout, had correlation coefficients of 0.20 or less, thus, indicating a random Cs^{137} to Sr^{90} correlation. $Cesium^{137}$ concentration was not determined on the milk samples from the 1958 survey.

The primary source of radionuclides which contaminated feed produced during 1959 near NTS, was redistributed fallout from earlier detonations at NTS rather than from stratospheric fallout of 1959. This conclusion was derived from the similarity of the Plumbbob and 1959 milk equations, relating the Cs^{137}-to-Sr^{90} ratio to Sr^{90}, to each other and to the equation for soils (Figures 8.6 and 8.2, respectively).

High Cs^{137}-to-Sr^{90} ratios in milk were associated with low Sr^{90} concentrations in Plumbbob and 1959 milk; and as the Sr^{90} concentration increased, there was a rapid decrease in the ratio (Figure 8.6). The correlation coefficients of -0.89 and -0.73 (significant at the 1 percent level) for the equations showed that these relationships were consistent.

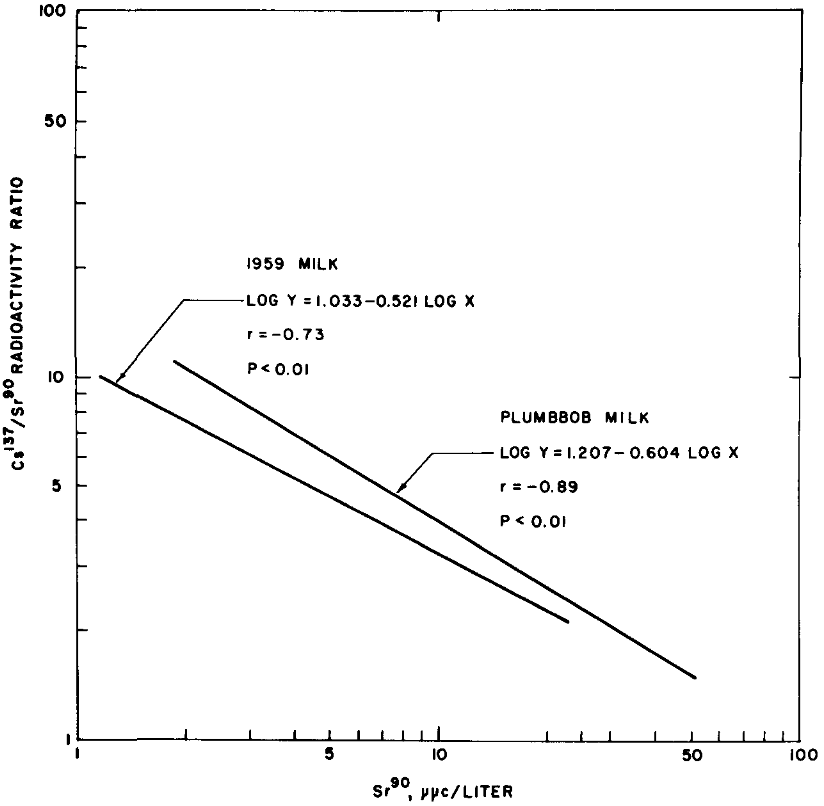

Figure 8.6 Relationship Between Cs^{137}-to-Sr^{90} Radioactivity Ratio and Sr^{90} of Milk Produced Either from 1959 Feed or After Shots Priscilla and Smoky.

8.2.4 $Strontium^{90}$ Deposition in the Smoky Fallout Pattern

The Sr^{90} deposited near the midline of the fallout pattern from Shot Smoky made a substantial increase in the Sr^{90} in surface soil of the NTS environs. At Panguitch and Antimony, 205 and 233 miles from ground zero, respectively, the Sr^{90} concentration from Smoky was more than one-third of the total postshot concentration (Table 8.7) even though Antimony was near the Met fallout pattern in 1955 (Reference 2).

TABLE 8.7 Sr^{90} in Surface Soil of Utah Farms After Smoky Fallout Deposition

Collection locations are given in Table 8.2. See method of Smoky Sr^{90} calculation in Section 8.2.4. Soil was 0-1 inch deep. The total Sr^{90} was determined after sodium carbonate fusion.

Collection Location	Collection Date	Field	Replicates Composited	mc/mi^2	
				Total Sr^{90}	Smoky Sr^{90}
Panguitch	D + 7	Pasture	5	50.7	18.6
Fremont	D + 9	Alfalfa	2	39.0	9.5
Antimony	D + 51	Alfalfa	3	25.2	9.6
Veyo	D + 59	Alfalfa	5	36.9	6.2

The Sr^{90} from Smoky fallout was calculated as the product of the surface soil beta activity from fallout (Table 8.8) multiplied by the Sr^{90}-to-beta ratio of isolated Smoky fallout particles (Table 5.5) corrected to H + 12 hours. In fallout deposited at a particular farm, the percentage of beta activity for each particle size range was obtained from the time of fallout arrival (Table 8.2) and the percentage of beta activity deposited in <44 micron particles (Table 3.2). For example, at Panguitch the time of fallout arrival was H + 11.8 hours; and 49 percent of the integrated beta activity deposited at H + 12 hours was in particles less than 44 microns in diameter, which had a Sr^{90}-to-beta ratio of 6.8 x 10^{-4} percent. The remaining 51 percent of the beta activity deposited at Panguitch was considered to be in particles between 44 and 88 microns, which had a Sr^{90}-to-beta ratio of 3.5 x 10^{-4} percent.

TABLE 8.8 Beta Activity in Surface Soils of Utah Farms Contaminated by Priscilla and Smoky Fallout

Collection locations are in Table 8.2. Soils were 0 to 1 inch deep, and 1 sq ft area. SD, standard deviation. (P), field plowed after D + 9. (S), Post-Priscilla beta activity subtracted.

Collection Location	Contaminating Shot	Collection Date	Field	Replicates	Beta activity at H + 12 hr μc/sq ft (Mean ± SD)	Dose rate at H + 12 hr mr/hr
Veyo	Priscilla	D + 16	Alfalfa	6	34.4 ± 4.8	6.8
		D + 20	Corn	2	45.5 ± 16.7	6.2
		D + 16	Pasture	3	43.2 ± 11.9	5.9
		D + 16	Virgin	6	59.7 ± 16.6	7.3
Antimony	Smoky	D + 51	Alfalfa	3	65 ± 2.3	
Fremont	Smoky	D + 9	Alfalfa	2	60.6 ± 9.9	14
			Potato	2	42.0 ± 6.6	12
			Pasture	1	80.0	20
		D + 50	Alfalfa	3	69 ± 35	
			Potato	3	13(P) ± 170	
			Pasture	2	101 ± 8	
			Virgin	3	97 ± 24	
Panguitch	Smoky	D + 7	Pasture	3	128 ± 50.4	24
		D + 51	Pasture	3	237 ± 40	
St. George	pre-Plumbbob	4/27/57	Alfalfa	3	0.011 ± 0.002	
	Smoky	D + 58	Alfalfa	3	46 ± 11	
Veyo	Smoky	D + 59	Alfalfa	6	54(S) ± 24	
			Corn	4	33(S) ± 19	
			Pasture	3	95(S) ± 37	
			Virgin	4	56(S) ± 43	

The Sr^{90}-to-beta ratio in a fallout particle mixture was the summation, for all particle size ranges, of the percentage of beta activity in the size range multiplied by the Sr^{90}-to-beta percent for that size range. At Panguitch the ratio was:

$$\Sigma\left(0.49 \times 6.8 \times 10^{-6} \frac{\mathrm{Sr}^{90}}{\mathrm{beta}}\right) + \left(0.51 \times 3.5 \times 10^{-6} \frac{\mathrm{Sr}^{90}}{\mathrm{beta}}\right)$$

The Sr^{90} deposited was,

$$128 \text{ beta, } \mu c/\text{sq ft} \times 5.2 \times 10^{-6} \frac{Sr^{90}}{\text{beta}} \times 2.79 \times 10^{7} \text{ sq ft/mi}^{2} \times 10^{-3} \text{ mc}/\mu c = 18.6 \text{ mc/mi}^{2}.$$

The percent of beta activity in the less than 44 micron particles was extended to the time of fallout arrival at Fremont by using the mean rate of increase in percentage of beta activity from H + 11 to H + 15 hours, 2.9 percent per hour. Soil collected at Veyo after Smoky fallout occurred had residual beta activity from Shot Priscilla which was subtracted to determine the beta activity from Smoky fallout.

8.2.5 Variation of Fallout Deposition on Farms in the Priscilla and Smoky Fallout Patterns

The beta activity from fallout of surface soil samples, taken soon after fallout deposition, differed significantly among adjoining fields with different crops within individual farms. Virgin soil from fence rows enclosing cropped fields and soil from irrigated native grass pastures had higher beta activities than soil from alfalfa or row cropped fields (Table 8.8). In the Priscilla fallout pattern at Veyo, Utah, virgin soil had more beta activity (significant at the 1 percent level) than soil from the adjacent alfalfa field. In the Smoky fallout pattern at Fremont, Utah, soil from a potato field was lower in beta activity (significant at the 1 percent level) than soil from the adjacent alfalfa field.

Gross activity, mr/hr at H + 12 hours, showed the same general differences between the surface soil activity of different fields of the same farm as did the beta activity of soil.

The Sr^{90} content of soil indicated that differences in fallout deposition among fields of the same farm was not an ephemeral condition due to fallout peculiarities of Shot Priscilla or Smoky but had existed for a relatively long time. At Veyo, Utah, surface samples of virgin soil were higher in Sr^{90} than samples from the enclosed alfalfa field (Table 8.9). The Sr^{90} in these soil samples represented the cumulative deposition of fallout from before 1951, essentially that after the Trinity detonation of 1945.

TABLE 8.9 Post-Priscilla Sr^{90} in Soil Samples at Veyo, Utah.

Soil was collected on D + 16. Sr^{90} was extracted by leaching with 6 N HCl. Six, one-quarter square foot samples composited for each analysis.

Depth sampled, Inches	Acid soluble Sr^{90} pc/sq ft	
	Alfalfa field	Virgin soil
0 to 1	310	430
1 to 2	151	150

The plant species growing in a field at the time of fallout deposition determined both the variability in deposition and the amount of fallout deposited onto soil in the field (Table 8.10). The sequence of fields of different crops according to beta activity of surface soil was:

Irrigated grass >corn (pre-tassel) >alfalfa >corn (mature) >potatoes.

The mean percent coefficients of variation by crops were: Corn, ± 47; Virgin soil, ± 44; Alfalfa, ± 26; Irrigated grass, ± 26; Potatoes, ± 16. (The mean percent coefficients of variation were derived from soil beta activity means and standard deviations of Table 8.8).

TABLE 8.10 Effect of Plant Species upon Surface Soil Contamination

Soil depth is 0 to 1 inch. Plants were at maximum leaf area development. The ratio is soil radioactivity units under field crop divided by soil radioactivity units under native grasses.

Plant Species	Beta Ratio	Sr^{90} Ratio
Native grasses	1.0	1.0
Alfalfa	0.7	0.7
Potatoes	0.5	--
Corn	0.4	--

Native grasses had a smooth surface appearance and projected a few inches high, and the early soil beta activity levels were consistently above those in neighboring fields with taller plants. The lowest amounts of fallout deposition were associated with row crops which were widely spaced relative to alfalfa or grasses. The Sr^{90} in surface soil from alfalfa fields and native grasses (Table 8.10) was similar to that of the beta activity.

There was a suggestion that the physical structure of the plants might have induced turbulence in the layer of air, adjacent to the ground surface. An increase in air turbulence, due to plant interference with air movement, would tend to increase the proportion of small particles that remained suspended and to reduce fallout deposition in that field, for deposition to another place where surface roughness was less. Plant retention of fallout (Section 8.2.6) was insufficient to cause the differences in deposition which were observed among the various fields.

The variability in the Sr^{90} of surface soil was similar to that of the beta activity. The variation in the Sr^{90} content of one small alfalfa field is shown in Table 8.11 after fallout deposition from both the Priscilla and Smoky detonations. In both cases the coefficients of variation were 34 percent.

TABLE 8.11 Sr^{90} Variation in Surface Soil Samples

Soil is 0 to 1 inch deep and one quarter square foot from an 8 acre alfalfa field at Veyo, Utah. Sr^{90} was determined by carbonate fusion. SD, standard deviation.

Site No.	Priscilla D + 16 pc Sr^{90}/sq ft	Smoky D + 59 pc Sr^{90}/sq ft
1	779	865
2	577	1080
3	860	--
4	1220	1120
5	1040	2010
6	1520	1550
Mean ± SD	999 ± 337	1325 ± 457

8.2.6 Fallout Retained by Plants

In cultivated areas investigated, agricultural plants retained less than 15 percent of the fallout deposited from Shot Smoky. Maximum retention occurred at 259 miles from ground zero: 12 percent of the fallout deposit was retained by alfalfa plants (Table 8.12). Alfalfa plants were more efficient in retaining fallout than grasses, when both were exposed at the same location. The percentage of fallout retained by both species was similar if measured in beta activity at H + 12 hours or as percent Sr^{90}.

The maximum beta activity on plants, 876 μc/kg, was measured closest to ground zero, i.e., 205 miles from ground zero in the Smoky fallout pattern (Table 8.12). At greater distances, or with increased time-of-fallout, the plant activity decreased.

The particle sizes retained by plants were those of less than 44 microns diameter in both the Smoky and Priscilla fallout patterns. The Sr^{90}-to-beta activity ratios of grasses collected from pastures in the Smoky fallout pattern by D + 9 days were almost identical with Sr^{90}-to-beta activity ratios of the less than 44 micron fallout particles (Section 8.2.4.). In previous studies in the vicinity of the Nevada Test Site, the fallout particle size retained by native forbs and shrubs was predominantly that less than 44 microns with a mean particle size of approximately 20 microns (Reference 4).

The amount of fallout retained by a plant species (μc/kg or μc/sq ft) decreased with an increase in the fallout time-of-arrival, but the percent of fallout retained increased. The fallout time-of-arrival affected both the intensity of fallout deposition and the diameter of fallout particles (Table 3.2). The combined effects, decreasing particle size and lower levels of fallout activity, were complexly interrelated in determining the resultant contamination of plants by fallout.

The retention of fallout (in μc/kg) varied between plant species. The beta activities retained by plants , directly contaminated by fallout, were, in decreasing order: native grasses > alfalfa > ensilage. Grasses at Fremont had the same beta activity level as

TABLE 8.12 Activity Retained by Plants Exposed to Fallout, Utah Farms

Collection locations are defined in Table 8.2. Surface soil beta activity is given in Table 8.8. Surface soil Sr^{90} activity is given in Table 8.7. Total activity was sum of soil and plant activities. NA, not available. H, harvest date.

Collection Location	Shot Fallout	Collection Date	Kind of Field Sample	Density gm/sq ft	Beta activity at H + 12 hr				Sr^{90}-to-Beta Ratio 10^{-4} pct
					µc/kg	Total µc/sq ft	Plants µc/sq ft	Retained pct	
Veyo	Priscilla	D + 16	Alfalfa Growing	43.3	8.3	34.7	0.29	0.84	NA
Fremont	Smoky	D + 9	Pasture Grasses	16.5	273	84.5	4.5	5.3	6.9
	Smoky	D + 9	Alfalfa Growing	27.9	288	68.7	8.1	12	NA
Panguitch	Smoky	D + 7	Pasture Grasses	5.6	876	133	5.0	3.8	6.4
Veyo	Priscilla + Smoky	D + 10	Alfalfa Growing	19.2	192	92	3.7	4.0	NA
Veyo	Priscilla	D + 16	Pasture Growing	NA	2.6	NA	NA	NA	NA
Antimony	Smoky	D + 5H	Alfalfa Baled	NA	321	NA	NA	NA	NA
Sr. George	Smoky	D + 9H	Alfalfa Baled	NA	33	NA	NA	NA	NA
	Smoky	D + 15H	Corn Ensilage	NA	26	NA	NA	NA	NA
Veyo	Smoky	D + 3H	Alfalfa Baled	NA	50	NA	NA	NA	NA
	Smoky	D + 15H	Corn Ensilage	NA	125	NA	NA	NA	NA
					Sr^{90} at H + 12 hr				
					uc/kg	mc/mi^2	mc/mi^2	pct	
Fremont	Smoky	D + 9	Pasture Grasses	16.5	5.6	10.6	0.86	8.3	6.9
Panguitch	Smoky	D + 7	Pasture Grasses	5.6	1.9	19.5	0.88	4.5	6.4

alfalfa, but there was 60 percent more alfalfa tissue (gm/sq ft) exposed to fallout than grass. The grass was a more efficient fallout collector on a kilogram basis but not on a square foot-area basis.

Density of plant material (gm/sq ft) was important in the retention of fallout. Plant beta activity was approximately proportional to plant density when different species in close proximity of each other were investigated.

The mean percent of fallout retention among the samples was less than 7 percent for beta activity and Sr^{90} in the Priscilla and Smoky fallout patterns. Alfalfa retained an average of 8 percent of the activity deposited and grasses retained 6 percent. When the weight of plants (gm/sq ft) was normalized to 20 gm/sq ft the percent retained was reversed with grasses averaging 12 percent and alfalfa averaging 6 percent for a mean of less than 9 percent for the observations in the Priscilla and Smoky fallout patterns.

8.2.7 Redistribution of Fallout After Deposition

Redistribution as used here, refers to a change in location from the site of initial deposition by either lateral or vertical movement.

The beta activity of surface soil at Panguitch approximately doubled (significant at the one percent level) between D + 7 and D + 51 days, a direct result of redeposition from the surrounding native area.

Clear evidence of fallout redistribution was given by alfalfa plants that grew in fields after a harvest had removed plants exposed to direct fallout. Based upon soil plus plant beta activity at sampling (Table 8.13) the percent of beta activity retained by alfalfa regrowth after D + 2 days varied from 6 percent to less than 1 percent. The beta activity (μc/kg) of regrowth of the crop ranged from 50 to 100 percent of the activity on plants which were in fallout on D day.

TABLE 8.13 Redistributed Fallout on Plants

Collection locations are defined in Table 8.2. Total beta activity was sum of soil and plant beta activity at sample collection. Beta activity of plants in fallout from Shots Priscilla and Smoky are given in Table 8.12. (p), post-Priscilla. (s), post-Smoky. NA, not available.

Collection Location	Regrowth		Plant Density, gm/sq ft	Beta activity, H + 12 hr μc/kg	Beta activity at collection, 10^{-4} μc/sq ft		Activity on Regrowth pct	
	From	To			Total	Plants	μc/kg	μc/sq ft
Veyo	D + 18	D + 40(p)	12.3	7.8	15	0.059	94	0.39
Antimony	D + 10	D + 51(s)	18.6	180	20	1.1	56	5.5
Fremont	D + 2	D + 49(s)	NA	137	NA	NA	48	NA
Sr. George	D + 10	D + 58(s)	19.5	16	9.0	0.077	48	0.86
Veyo	D + 3	D + 57(s)	15.6	62	12	0.25	125	2.1

The D + 3 to D + 20 day data showed aerosol concentrations following Shots Priscilla and Smoky (Section 6.2.6) were high enough to contaminate new plant growth to levels equal to that of plants exposed to cloud debris of Priscilla and equal to half that of plants exposed to Smoky debris. It was not uncommon to find NTS debris as a substantial contributor to the contamination of 1959 dairy forages (Section 8.2.3).

For alfalfa regrowth utilized as forage by dairy cattle at Fremont, Utah on D + 49 days, the Sr^{90}-to-beta ratio was 8.0×10^{-4} percent, which was identical to that ratio of less than 5 micron fallout debris from the Smoky detonation and which could have occurred only from the redistribution of fallout. Stratospheric fallout was not the primary source of contamination associated with alfalfa regrowth in the post-Smoky period. Stratospheric fallout has been shown to be essentially proportional to precipitation (Reference 5). Weather Bureau records of precipitation in the vicinity of all farms in this study during the regrowth of alfalfa were inversely proportional to the contamination level of the regrowth material; precipitation was highest where the plant activities were lowest and conversely. Thus, stratospheric fallout was not responsible for the major portion of the activity contaminating plant regrowth.

The coefficient of variation for soil beta activity which increased with time also suggests redistribution. The coefficients were approximately doubled in the period after D + 48 days compared to those before D + 20 days for an entire farm, but the increases were not consistent within individual fields (Table 8.8). However, increasing variability may have been due in part to the redistribution of fallout particles by irrigation and rainfall erosion, however, not all fields were irrigated.

The vertical distribution of Cs^{137} in soil profiles was quite different from those of the naturally occurring thorium and K^{40} activity. Distribution of the naturally occurring thorium was more like that of K^{40} than that of Cs^{137} (Table 8.14). $Potassium^{40}$ was distributed the most uniformly in soil profiles. Half the manmade Cs^{137} was in the 0 to 1 inch increment. These fields were not plowed after Operation Upshot/Knothole, and it was surprising to find half of the cesium below the surface inch of soil. However, the percent distribution of Cs^{137} left little doubt that its movement was through the soil profile.

There was little change in the activity of subsoils between sample collections which was interpreted as showing that the surface persistence of fallout was high when subjected to aqueous solution by irrigation of cultivated fields. At Veyo, Utah (Table 8.9) the gross transfer of acid-soluble Sr^{90} from the soil surface in the alfalfa field to the 1 to 2 inch depth was 8 percent greater than in the virgin soil adjacent to it. Both fields had the same rainfall, but approximately 42 feet of irrigation water was applied to the alfalfa field after the last plowing. Under these conditions irrigation had little effect upon Sr^{90} migration into subsurface soil, indicating that its persistence on the surface was high.

TABLE 8.14 Vertical Distribution of Three Gamma Emitters in Soil Profiles

Average at two Utah farms in October 1957 at 135 miles from NTS. Each replicate one square foot area.

Soil depth, inches	Pct Isotope per Increment		
	ThO_2	K^{40}	Cs^{137}
0 to 1	20.7	16.7	45.0
1 to 2	16.9	15.2	19.5
2 to 3	15.5	15.8	14.7
3 to 4	15.3	17.7	10.8
4 to 5	16.4	18.0	4.7
5 to 6	15.2	16.3	5.5

In fields from the Smoky fallout pattern, the beta activity of subsoils was significantly lower than that of surface soils and was relatively uniform from 1 to 6 inches deep where the fields had not been plowed or leveled recently (Tables 8.15 and 8.16). The beta activity of pre-Plumbbob surface soils was similar to that of their subsoils. These observations affirm the suitability of subsoil beta activity as a substitute for the prefallout surface soil beta activity in recent fallout pattern deposits.

TABLE 8.15 Vertical Distribution of Beta Activity in Soil Profiles, Utah Farms

Collection locations are defined in Table 8.2. Three replicates were averaged except at Fremont on D + 9 where two were averaged. Each replicate was one square foot in area. L, difference from beta activity in next lower increment significant at the 5 percent level. H, difference from beta activity in next lower increment significant at the 1 percent level.

	Management and Radiological History of Fields								
Location	Veyo		St. George		Fremont		Panguitch		Antimony
Field	Alfalfa		Alfalfa		Alfalfa		Pasture		Alfalfa
Last plowed	Before 1951		1953		Before 1955		Before 1937		1952
Contaminating shot	Priscilla	Smoky	---	Smoky	Smoky	Smoky	Smoky	Smoky	Smoky
Date sampled	D + 16	D + 59	4/27/57	D + 58	D + 9	D + 49	D + 7	D + 51	D + 51
Date radioassayed	12/10/57	12/9/57	12/13/57	12/12/57	12/11/57	12/13/57	12/11/57	12/11/57	12/10/57
Depth sampled, inches	Beta activity at time of radioassay, μc/sq ft								
0 to 1	0.068	0.125L	0.059	0.004H	0.166H	0.145L	0.211L	0.337H	0.125
1 to 2	0.058	0.064	0.050	0.064	0.069	0.076	0.065	0.062	0.053
2 to 3	0.048	0.061	0.050	0.067	--	0.078	--	0.059	0.056
3 to 4	0.049	0.057	0.065	0.062	--	0.074	--	0.058	0.054
4 to 5	0.059	0.049	0.060	0.068	--	0.065	--	0.061	0.052
5 to 6	0.047	0.045	0.048	0.073	--	0.067	--	0.061	0.051

TABLE 8.16 Vertical Distribution of Beta Activity in Soil Profiles, Nevada Farms

Collection locations defined in Table 8.2. Three replicates were averaged except at Alamo where two were averaged. Each replicate was one square foot in area.

	Management and Radiological History of Fields							
Location	Alamo		Alamo		Lund		Pahrump	
Field	Corn		Alfalfa		Alfalfa		Alfalfa	
Last plowed	Surface-Leveled 4/57		1954		1954		1954	
Date sampled	5/2/57	10/31/57	5/2/57	10/31/57	5/2/57	11/4/57	5/9/57	11/1/57
Date radioassayed	12/5/57	12/ 9/57	12/ 5/57	12/ 9/57	1/17/58	1/23/58	12/19/57	1/10/58
Depth sampled, inches	Beta activity at time of radioassay, μc/sq ft							
0 to 1	0.073	0.120	0.081	0.091	0.063	0.098	0.047	0.049
1 to 2	0.084	0.098	0.090	0.080	0.061	0.059	0.052	0.050
2 to 3	0.087	0.094	0.083	0.080	0.057	0.060	0.046	0.052
3 to 4	0.102	0.095	0.082	0.080	0.063	0.057	0.056	0.051
4 to 5	0.100	0.106	0.083	0.088	0.061	0.055	0.058	0.054
5 to 6	0.074	0.127	0.088	0.093	0.061	0.058	0.061	0.057

8.2.8 Fallout Relationships in Dairy Operations

Hay and forage crops were highest in picocuries of Sr^{90}/kg of the feeds used for milk production and these supplied most of the dietary Sr^{90} (Tables 8.17 and 8.18). Dietary calcium varied from normal to very high levels and was effective in making Milk-diet observed ratios, OR, to be explained subsequently, different at the dairies studied. The data used for intensive comparisons were oriented toward determining the biological significance of fallout from the Shots Priscilla and Smoky.

TABLE 8.17 Sr^{90}, Calcium, and Stable Strontium in Utah Dairy Feeds

C, digestible nutrients needed to supplement hay to maintain milk production Reference 3.

Collection Location	Collection Date	Feed Component Oven-dried	Consumption per cow kg/day	Sr^{90} pc/kg	Sr/kg, mg	Ca/kg, gm	Sr^{90}/Ca pc/gm	Milking Herd, Cows
			Pre-Plumbbob Feeds					
Veyo	9/10/57	Concentrates	5	52.5	19.3	6.0	8.8	30
		1956 hay	18	667	195	30.5	21.9	
		Feces		1050	334	32.5	32.3	
			Priscilla Pattern					
Veyo	D + 15	Concentrates	5	58.5	52	4.04	14.5	25
	D + 15	1956 hay	12	667	195	30.5	21.9	
	D + 16	Forage, mixed	6^c	453	89.4	16.5	27.4	
	D + 15	Feces		860	250	31.0	27.7	
			Smoky Pattern					
Panguitch	D + 8	Concentrates	1	27	8.0	0.580	47	2
	D + 7	Forage, grasses	14^c	5,600	46	6.94	807	
	D + 7	Feces		16,700	188	29.6	564	
Fremont	D + 9	Concentrates	1/2	82	12	0.680	121	7
		1956 hay	1 1/2	1,740	68.7	12.0	145	
		Forage, grasses	8^c	1,880	84.7	3.67	512	
		Feces		4,900	211	22.6	217	
Fremont	D + 49	Beet pulp	1/2	58.9	119	1.77	33.3	5
		Concentrates	1	32.4	13.3	1.25	25.9	
		Forage, alfalfa	11^c	1,110	279	16.1	68.9	
		Feces		2,960	407	55.1	53.7	

TABLE 8.18 Daily Consumption of Sr^{90}, Calcium, and Stable Strontium by Utah Dairy Cattle

Collection Location	Collection Date	Component Oven-dried	Sr^{90} Ingested, pc/cow/day	Calcium Ingested, gm/cow/day	Stable Strontium Ingested, gm/cow/day	Sr^{90} in milk, pc/liter	Milk, liters/day
Pre Plumbbob Feeds							
Veyo	9/10/57	Concentrates	263	30	0.097		
		1956 hay	12,000	549	3.510		
		Total	12,300	579	3.61	4.27	352
Priscilla Fallout Pattern							
Veyo	D + 15	Concentrates	293	20	0.260		
		1956 Hay	8,000	366	2.34		
		Mixed forage	2,720	99	0.536		
		Total	11,000	485	3.14	7.1	396
Smoky Fallout Pattern							
Panguitch	D + 8	Concentrates	27	0.6	0.008		
		Grass forage	78,400	97.2	0.644		
		Total	78,400	98	0.652	51.8	20
Fremont	D + 9	Concentrates	41	0.3	0.006		
		1956 Hay	2,610	18.0	0.103		
		Grass forage	15,000	29.4	0.676		
		Total	17,700	47.7	0.785	13.4	79
Fremont	D + 49	Beet pulp	29	0.9	0.060		
		Concentrates	32	1.3	0.013		
		Alfalfa forage	12,200	177	3.07		
		Total	12,300	179	3.14	5.72	66

The Sr^{90} in fallout from Shot Priscilla was twice as available as Sr^{90} from Shot Smoky, whether measured as percentage in milk from the diet or as normalized ratios corrected for differences in milk production (Table 8.19). Normalizing procedures were based on studies which demonstrated that the percentage of dietary Sr^{90} per liter was constant (Reference 6) and which made comparisons of availability easier to interpret. Excluding dietary calcium as a component of the availability of dietary Sr^{90}, the Sr^{90} in fallout from Shot Smoky was similar in availability to fallout contaminating 1956 feeds.

TABLE 8.19 Availability of Fallout Sr^{90} to Dairy Cattle

The percent diet Sr^{90} in milk divided by the percent 1956 dietary Sr^{90} in milk is defined as relative availability. Ten liters per day per cow divided by the liters per day per cow produced is normalized production.

Principal Sr^{90} Source	$\frac{\text{Sr}^{90}\text{ in Diet}}{\text{Sr}^{90}\text{ in Milk}}$	Relative Availability Observed	Relative Availability Normalized
1956 Fallout	246	1.0	1.0
Smoky Fallout (H + 12 hr)	151	1.6	1.0
Resuspended Smoky (D + 49)	163	1.5	1.3
Smoky Fallout (H + 17 hr)	117	2.1	2.2
Priscilla Fallout (H + 7 hr)	41	6.0	4.5

Dairy cattle were able to extract the Sr^{90} from fallout debris contaminating their feeds in the same proportions as it occurred in the fallout particles (Table 8.20). This observation indicated that the digestive processes of ruminants were more severe than leaching the particles with 1 N HCl.

TABLE 8.20 Comparison of Strontium Solubility and Biological Availability

Milk production is normalized to 10 liters per day per cow. Production is given in Table 8.18.

Comparison Ratio	Strontium	Solvent Used None	 0.1 N HCl	 H_2O
	Priscilla-to-Smoky Ratios			
<44 μ Particles	$Sr^{89,90}$	2.5	4 +	18
Milk pc/Diet pc	Sr^{90}	2.9-3.7	--	--
Milk pc/Diet pc (Normalized)	Sr^{90}	2.0-2.4	--	--

The percentage of dietary calcium and stable strontium in the cattle feeds varied by a factor of five in the study without clear relationships existing with the percentage of dietary Sr^{90} secreted into milk (Table 8.21). If fallout from Shot Priscilla were excluded, the conversion of dietary Sr^{90} into milk decreased as the percent of dietary calcium increased.

The Sr^{90}-to-calcium ratio in milk divided by the Sr^{90}-to-calcium ratio in the diet was suggested as a biological constant that expressed the discrimination by biological membranes against strontium relative to calcium (Reference 7). The quotient of the two ratios was called the Observed Ratio (OR) and has been widely used in predictions of the hazard imposed by fallout debris entering food chains. The Observed Ratios (milk-to-diet) in this study varied by a factor of ten and were not suitable for use as a constant to describe the discrimination against strontium (Table 8.21).

TABLE 8.21 Sr^{90} in Milk and Observed Ratios as Functions of Dietary Calcium and Stable Strontium

P, forage contaminated by fallout from Shot Priscilla. OR, Observed Ratio, percent dietary Sr^{90} in milk divided by percent dietary calcium in milk.

Percent of Elements Observed in Dairy Diets Calcium	 Stable Strontium	Milk-to-Diet Sr^{90} Ratio x 10^{-4}	OR, Milk-to-diet
0.48	0.0079	85	0.03
0.65	0.0043	66	0.05
1.43	0.025	61	0.07
2.11	0.014	102P	0.31
2.52	0.016	41	0.18

When the dietary calcium of dairy cattle was at normal levels, the fallout Sr^{90} was more available than was stable strontium both of which were accumulated through plant roots; but the fallout Sr^{90} was less available when dietary calcium was high (Table 8.22). High calcium percentages were associated with alfalfa and normal percentages with grass forage. It might be desirable to recommend calcium supplements for dairy cattle on grass pastures to reduce the Sr^{90} in milk by reducing the availability of fallout Sr^{90}.

TABLE 8.22 Availability Comparison of the Stable Strontium and Fallout Sr^{90}

Milk data normalized to correct for differences in volume produced

Percent of Calcium in diet		Stable Sr Availability Ratios	Relative Availability
Normal	High	$\frac{\text{Strontium in diet}}{\text{Strontium in milk}}$	$\frac{\text{Stable Strontium Ratio}}{Sr^{90}\text{ ratio}}$
	2.10	403	6.2
	1.43	331	1.6
	2.52	362	1.3
0.65		111	0.74
0.48		81	0.61

The amount of Sr^{90} metabolized into milk increased in proportion to increases in Sr^{90} consumption, but the relationship was affected by other variables since the extrapolation to zero Sr^{90} in the diet did not pass through the origin (Figure 8.7). However, the percentages of Sr^{90} carried into milk were relatively uniform, varying by a factor of two (Figure 8.8), contrary to the amounts in daily milk. Forage contaminated by direct fallout from passage of a nuclear cloud had been used for at least 8 days at all dairies and equilibrium should have been attained between Sr^{90} intake and Sr^{90} in milk by the time of sample collection (Reference 8).

The amount of calcium in daily milk appeared to be relatively independent of the amount consumed and approximated a constant value (Figure 8.7). Percentages of calcium metabolized into milk from the diets had a striking inverse relationship with dietary calcium (Figure 8.8).

The calcium content of milk is physiologically restricted to a narrow range and is approximately a constant. Dietary calcium varied by more than an order of magnitude (Table 8.21). Expressing milk calcium as percentages of dietary calcium in effect divided a constant by a variable with an order of magnitude range and resulted in order of magnitude differences among the percentages. This characteristic of milk calcium percentages was a significant factor in the variability of the OR among the dairies.

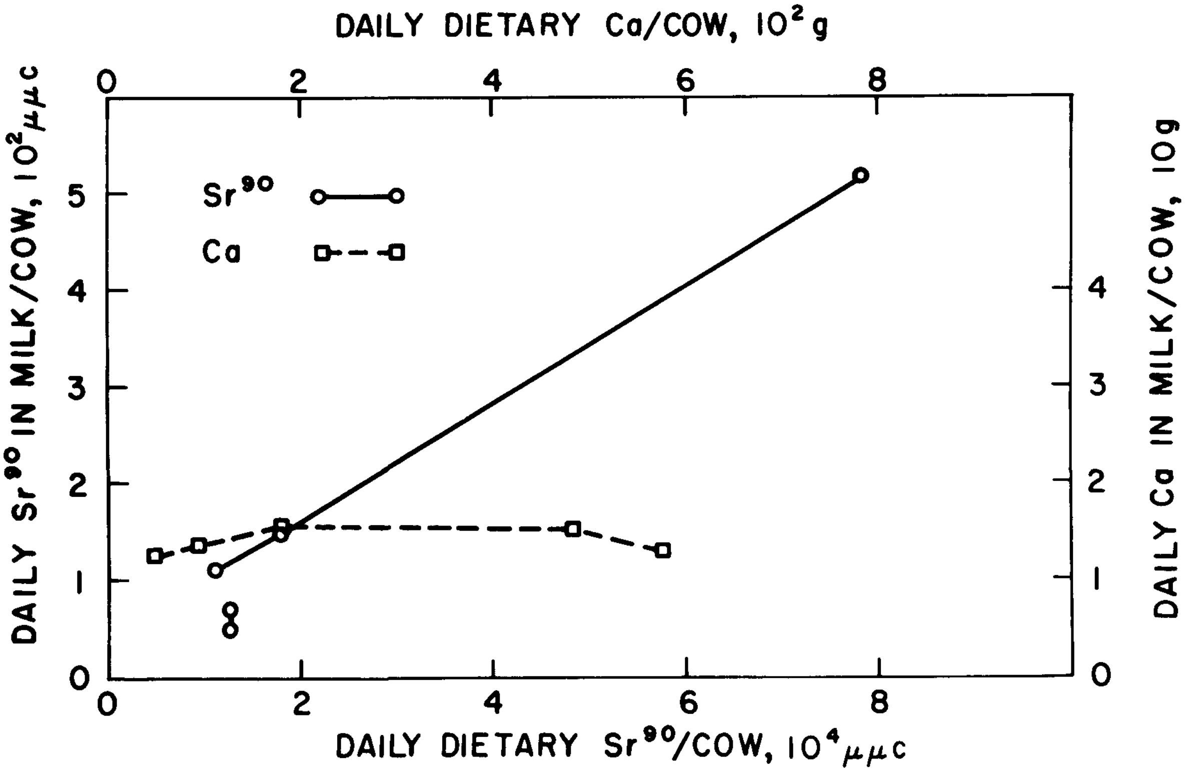

Figure 8.7 Amounts of Sr^{90} and Calcium Metabolized into Milk from Diets with Different Amounts of Sr^{90} and Calcium.

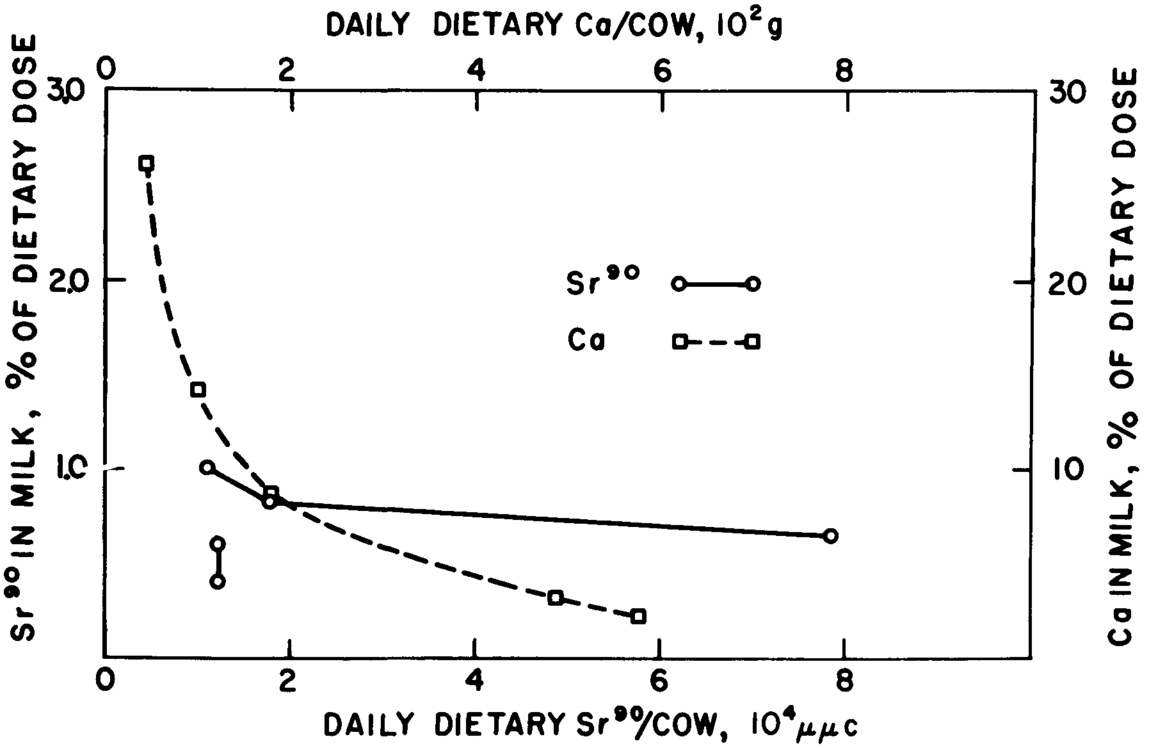

Figure 8.8 Percents of Sr^{90} and Calcium Metabolized into Milk.

Although the OR was defined as the ratio of strontium units in milk divided by the strontium units in the diet (Reference 7), it can also be calculated as the percentage of dietary Sr^{90} in milk divided by the percentage of dietary calcium in milk. Expressed this way it is apparent that increases in dietary calcium, above the needs for milk production and body maintenance, will decrease the percentage of dietary calcium in milk linearly with the calcium increases. Observed Ratios obtained under these conditions are calculated with progressively smaller percentages of dietary calcium in milk and must increase with dietary increases.

As the percentage of calcium in the dairy diets increased, the OR went up (Table 8.21). The percentage of dietary Sr^{90} in milk decreased to one-half while the percentage of dietary calcium in milk decreased to one-twelfth, resulting in an increase in the OR by a factor of six. Data from Shot Priscilla fit this trend if the percentages of Sr^{90} in milk and the OR corrected for the higher availability of Sr^{90} (Table 8.20). The increases in OR were almost linear with the increases in percentage of dietary calcium. The OR determinations were by no means a biological constant under conditions prevailing in the NTS region.

Above 0.65 percent dietary calcium, the feces-to-diet OR was greater than 1.0 indicating that the cattle were in equilibrium with their diets. At or below 0.65 percent dietary calcium, the feces-to-diet OR was approximately 0.40 which was interpreted as indicating withdrawal of calcium from body stores for milk production. Below 2 percent dietary calcium, the feces-to-diet OR for Sr^{90} was approximately 0.65 indicating that the cattle were not yet in equilibrium with their diets, and suggesting that the availability of dietary calcium was low or that 8 days were insufficient to attain equilibrium with fallout debris.

8.3 SUMMARY

The general level of soil Sr^{90} was quite variable whether measured by acid extraction or by total fusion methods. There was little agreement between either data available on fallout intensity or distance from ground zero and soil Sr^{90} measured by fusion analyses. The acid solubility of soil Sr^{90} was lowest where Sr^{90} concentration was highest and vice versa.

The soil Cs^{137}-to-Sr^{90} ratios were quite variable and not linearly related to soil Sr^{90} concentration. The Cs^{137}-to-Sr^{90} ratios of fallout particles from tower mounted Shot Smoky were 12 to 40 percent of the theoretical ratio.

Evidence of significant redistribution of NTS fallout was given by data from surface soil, plants, and milk; some soil and plant beta activity values approached the amounts originally deposited after individual detonations.

The Sr^{90} and Cs^{137} in 1956, 1957, and 1959 milk indicated that NTS debris was providing significant amounts of the fission products contaminating plants 1 and 2 years after testing. The amounts of redistributed fission products were gradually decreasing. Redistribution at the midlines was decreasing to nonmidline levels.

Agricultural plants retained less than 15 percent of the fallout from Shot Smoky. The absolute quantity decreased with increasing time of fallout arrival, though the percentages of beta activity and Sr^{90} retained increased.

There were significant differences in deposition of fallout onto soil at individual farms. These differences were closely related to the kind of plant cover occupying the fields whether measured in mr/hr, μc/sq ft of beta activity or as mc Sr^{90}/mi^2.

The Sr^{90}-to-beta ratios of green plants exposed to fallout were very similar to those of the less than 44 micron fallout particles recovered from granular collectors.

The Sr^{90} in milk was a function of dietary levels; but the relationship was not linear with dietary Sr^{90}, calcium, or stable strontium.

At higher levels of Sr^{90} in milk, the Cs^{137} approached concentrations equivalent to those of the Sr^{90} in 1957 and 1959 milk.

The biological availability of Sr^{90} from fallout was quite variable in percentage and for times of fallout deposition after H + 5 hours, agreed better with the total Sr^{90} in particles from Smoky and Priscilla detonations than with particle solubility.

A wide range was found in the Observed Ratio (0.03 to 0.30) for fallout from different sources.

The availability of Sr^{90} in fallout particles adhering to plants was greater than that of stable strontium inside plants where dietary calcium was normal. The converse was true at high calcium levels.

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CHAPTER 9

SUMMARY

During the period 1947 to 1963 the Environmental Radiation Division of the Laboratory of Nuclear Medicine and Radiation Biology, School of Medicine, U.C.L.A [1] was involved in progressively intensified programs designed to answer one principal question, viz., "How much man-made radioactivity distributed in the environment can be tolerated safely by man and his economy?" Within this broad context, the general objectives of Civil Effects Test Organization Program 37 included:

(a) The delineation of fallout patterns and their characteristics with respect to particle size and time-of-arrival of fallout from seven tower mounted and four balloon mounted detonations. Comparison of the effects of the yield of the device, the type of device support, and the height of burst on the resultant fallout debris deposited within the fallout pattern to distances at which fallout occurred by H + 12 to H + 16 hours.

(b) A detailed study of the chemical, physical, and radiological characteristics of fallout debris relative to its particle size and occurrence within the fallout pattern.

(c) The determination of the biotic availability, rate of accumulation, and retention of radionuclides from fallout debris for various native and domestic plants and animals, as well as the persistence and redistribution of residual contamination in the total environment.

9.1 FALLOUT: ITS DISTRIBUTION AND CHARACTERISTICS

Fallout from test devices detonated at Nevada Test Site (NTS) is governed by many complex variables such as : (a) the energy yield of the detonation, (b) the wind structure during the distribution of fallout material, (c) the support used for the detonation of devices, (d) the nature of the surface at ground zero, (e) the degree that the fireball intersects the ground surface, and (f) the mass of inert material surrounding the device. Data presenting the resultant deposition and characteristics of fallout from various detonations studied by the AEP/UCLA laboratory are summarized in the following statements.

1. Characteristics of Fallout Patterns: The coordination of aerial survey measurements of fallout patterns with ground survey parties using conventional meter measurements greatly increased the detail and accuracy of fallout pattern delineation, as well as increasing the distances to which fallout patterns were defined in the environs of NTS. Dose rates and time-of-arrival of fallout resulting from Shots Boltzmann,

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[1] During the Plumbbob Test Series, the organization was known as EnRad, AEP/UCLA (EnRad, Atomic Energy Project, University of California at Los Angeles)

Wilson, Priscilla, Hood, Diablo, Shasta, Smoky, Galileo, Newton and Whitney were measured and are presented in terms of isodose rate and time-of-arrival on fallout contour maps.

With the adaptation of the aerial survey equipment and techniques developed by the U. S. Geological Survey, fallout radiation intensities could be measured within an area of approximately 10,000 square miles and the readings plotted on maps in about 12 hours by using one aircraft. With appropriate correction and calibration factors, aerial measurements agreed within ± 10 percent of dose rate measurements made 3 feet above ground by conventional survey meters. During this Test Series, fallout patterns were routinely measured to distances of 200 to 300 miles from ground zero, however, the fallout pattern from Shot Smoky was documented as far as 700 miles from ground zero in 5 flight-days and the radiation levels were readily detectable at that distance.

The detailed documentation of fallout patterns afforded the opportunity to confirm the existence of hot spots in most fallout patterns. Hot spots were first identified and defined in 1948 by the Alamogordo Section of AEP/UCLA when the fallout pattern of Shot Trinity (1945), New Mexico had been outlined in detail.

In the authors' opinion, terrain features, such as mountain ridges, create a significant turbulence in the falling radioactive debris as the cloud moves over the ridge causing increased deposition of fallout to occur on the leeward side. Suggestions of this phenomenon were found in the patterns of Shots Boltzmann, Priscilla, Hood, Diablo, and Smoky. Although rainouts have been reported to be responsible for hot spots within 300 miles of NTS, the documented hot spots referred to in this report occurred when no precipitation occurred during fallout.

While the occurrence of hot spots has been associated with prominent terrain features in many cases, a coordinated detailed analysis of the meteorological observations and fallout distribution is required to fully explain the mechanism of their formation and possibly to permit the prediction of their occurrence.

2. Particle Size Distribution in Fallout Patterns: Maximum percentage contributions of various particle sizes occurred at different locations on fallout pattern arcs. Some locations of maximum dose rate across a pattern resulted from moderate percentages of a variety of particle sizes rather than a high percentage of a single size range. Lateral extremities of arcs were characterized by high percentages of less than 44 micron material.

Fallout material less than 44 microns in diameter occurred at close-in arcs as well as at distant arcs while the 44 to 88 micron fraction of fallout material was minimal at close-in distances. The majority of fallout activity from the balloon mounted Shot Priscilla consisted of particles less than 44 microns in diameter as close to ground zero as 18 miles, larger particles predominated at such distances in fallout material from tower mounted shots.

Within the fallout area determined by the limits of 1 mile from ground zero to distances at which fallout occurred at H + 12 hours and the 1 mr/hr iso-intensity contour at H + 12 hours approximately 70 percent of the fallout activity was associated with particle sizes greater than 44 microns in diameter from tower mounted shots while the balloon mounted Shot Priscilla had only 30 percent of the activity associated with this size range of larger than 44 microns.

Within the limits of H + 1 to H + 12 hour fallout time, Shot Smoky deposited 52 times more total beta radioactivity and 14 times more radioactivity in the less than 44 micron fraction than Shot Priscilla. Both shots had similar yields and identical detonation height.

3. Radioactive Decay of Fallout Debris: Fallout debris from a specific detonation gave similar beta decay curves regardless of particle size or time of fallout. Beta decay curves of most detonations approximated the $T^{-1.2}$ decay relationship over a period of H + 12 to H + 6000 hours. However, slopes of the order of $T^{-1.4}$ occurred from H + 6000 to H + 10,000 hours.

Decay curves of the gamma emission rate were different from those of beta decay for fallout debris from a specific detonation. Gamma decay curves of fallout debris from different detonations were generally similar but more variable than the corresponding beta decay curves.

Plumbbob beta and gamma decay curves, derived from measurements of fallout samples from seven detonation, are presented in relation to the $T^{-1.2}$ decay curve and a theoretical mixed fission product (U^{235}) decay curve.

Estimates of dosage from gamma radiation in fallout areas have generally been calculated on the basis of the $T^{-1.2}$ relationship. However, dose rate decline with time according to the Plumbbob gamma decay (PGD) curve presented in this report yields calculated doses which are 1.8 to 2 times greater than those calculated by the $T^{-1.2}$ relationship to approximately D + 400 days.

4. Gamma Energy Spectrum of Fallout Debris: Samples of different particle size fractions and/or fallout time from each of five detonations were analyzed periodically to H + 3000 hours. Differences in the energy spectra were not detectable among samples of different particle size from a specific detonation; however, differences were detectable among several detonations. Mean energy spectra of fallout material from three detonations indicated that values increased from 0.53 Mev at H + 100 hours to 0.70 Mev at H + 600 hours and ranged from 0.74 to 0.87 Mev at H + 3000 hours. In contrast, the mean energy of the fallout debris from Shot Hood was approximately twice that of the other detonations at H + 100 hours but decreased to similar values of the other detonations after H + 1200 hours.

The general variation in energy spectrum with time suggests that considerable error can be introduced in the calculations of gamma megacuries from dose rate depending on type of detonation and time of measurement. On the basis of data presented, gamma megacuries per square mile values calculated according to the relationship of 4 r/hr at 3 feet above the ground surface that was used before 1962, would have been 75 percent too high for a detonation similar to Shot Hood and 25 percent too low for detonations like Shots Diablo and Shasta.

5. Radiochemical Properties of Fallout Debris: Fallout particles less than 44 microns in diameter had greater percentages of $Sr^{89, 90}$ and $Ru^{103, 106}$ at D + 30 days than did the larger sized particles. The percentage of $Sr^{89, 90}$ and $Ru^{103, 106}$ in balloon mounted detonation fallout debris was from two to four times higher than it was in corresponding particle sizes from tower mounted detonations. The reverse was observed for Zr^{95}. The percentage of Ba^{140}, Ce^{141}, and Y^{91} varied to a lesser degree between fallout from tower and balloon mounted detonations. $Strontium^{90}$ averaged 2.7 percent of the total radiostrontium at D + 30 days in fallout originating from detonations mounted on towers.

Similar percentage values for specific radionuclides among the same size fractions of the different tower shots permit the determination of mean percentage values descriptive of tower shots in general. The comparison of mean tower shot percentages to those of Shot Priscilla, a balloon mounted device, indicates that for corresponding size fractions Priscilla radionuclide percentages were approximately 30 percent higher for Ba^{140}, 11 to 38 percent higher for Ce^{141} + $Ce\text{-}Pr^{144}$, 300 to 400 percent higher for $Ru^{103, 106}$, 250 percent higher for Sr^{89}, 20 to 50 percent higher for Y^{91}, and 50 percent lower for Zr^{95}.

6. Solubility of Fallout Debris: Solubility of fallout debris is one of the most important properties to consider with respect to the "internal emitter" problem in biological systems. The solubility of radioactive fallout debris in water and in 0.1 N hydrochloric acid (HCl) have been used arbitrarily as indices of biological availability.

The radioactivity in fallout debris from tower mounted detonations was determined to be from 1 to 2 percent soluble in water. Fallout debris from balloon supported detonations was more soluble in both water and 0.1 N HCl than debris produced by tower mounted detonations. The solubility of fallout debris from tower supported detonations increased with decreasing particle size; however, in the case of balloon supported detonations, the smaller size particles were somewhat less soluble than larger particles as shown in Table 9.1.

7. Comparison of Fallout Debris from Balloon and from Tower Shots: A comparison was made of fallout debris from a balloon mounted shot (Priscilla) with that from a tower mounted shot (Smoky). These shots were of the same yield and had the

TABLE 9.1 Solubility of Fallout Debris from Tower and Balloon Supported Shots

Support	Particle Size Range, Microns	Solubility, Water	Pct of Beta Activity 0.1 N HCl
Tower	>44	< 1	5
	<44	< 2	14 to 36
Balloon	>44	31	>90
	<44	14	>60

same detonation height of 700 feet. The comparison indicated that the amounts of water soluble Ba^{140} and $Sr^{89, 90}$ deposited in the less than 44 micron particle size fraction were similar despite relatively large differences in the total amounts of radioactivity deposited in this particle size fraction.

The widespread distribution of the less than 44 micron particle size fraction from all types of devices detonated at NTS indicates that this particle size fraction is probably the most significant with respect to total area contaminated. Assuming that the soluble fractions of the fallout debris samples studied contain the same ratio of radioelements as that present in the original fallout debris, the application of this ratio to the percent of the soluble activity yields the percent of the various radioelements present in the 0.1 N HCl and water-soluble extracts. Based on such calculations, the relative amounts of the several radioelements in the soluble fractions of equal quantities of less than 44 micron fallout debris from tower and balloon supported shots of similar yield and height of detonation are presented.

The deposition of less than 44 micron fallout debris from the tower mounted detonation considerably exceeded that from the balloon mounted at different fallout times from one to fifteen hours.

The application of soluble radioelement percentages to the measured and the integrated radioactivities of the less than 44 micron particle size fractions from the two shots, Priscilla and Smoky, gives an estimate of the relative amounts of the various radioelements deposited at different fallout times. While the amounts of total and acid-soluble Ba^{140} and $Sr^{89, 90}$ deposited by less than 44 micron fallout debris from the tower mounted shot were higher over the 1 to 15 hour fallout period, the amounts of water-soluble Ba^{140} and $Sr^{89, 90}$ were similar.

8. Deposition of Radiostrontium in the Environs of Nevada Test Site: Approximately 0.13 percent of the total amount of Sr^{89} produced by Shot Priscilla (700 feet) whose fireball very nearly intersected the ground surface, was deposited within the fallout time-of-arrival of H + 12 hours. On the other hand only 0.004 and 0.008 percent

of the total Sr^{89} produced was deposited within H + 12 hours fallout time by two balloon mounted shots (1500 feet) whose fireballs did not intersect the ground. Within H + 12 hours fallout time, tower mounted shots deposited from 0.5 to 2 percent of the Sr^{89} produced and from 1.6 to 7.2 percent of the total Sr^{90} produced.* Calculations were based on the results of analyses of fallout debris samples for Sr^{89} and Sr^{90} and integrated fallout radiation intensities converted to curies by ratios of microcuries per square foot and milliroentgens per hour. The analysis of balloon detonation fallout debris for Sr^{90} was not performed.

The tower shot percentage deposition of Sr^{89} was less than that of Sr^{90} out to distances corresponding to H + 12 hour fallout arrival time. This is attributed to relatively low percentages of Sr^{89} in larger fallout particle size fractions which generally represent the majority of the fallout radioactivity in areas close to ground zero. This fractionation of Sr^{89} and Sr^{90} with respect to particle size may be predicted on the basis of the different half-lives of their noble gas precursors, Kr^{89} and Kr^{90}, respectively, and the rate of particle formation.

9.2 BIOLOGICAL AVAILABILITY OF FALLOUT DEBRIS IN FALLOUT PATTERNS FROM NEVADA TEST SITE

1. Distribution and Redistribution of Fallout Debris in Soils: Surface deposited fallout debris tends to become mechanically trapped in nonagricultural soil. Natural disturbance by wind action causes minor amounts of the total fallout debris, deposited in various native areas studied, to be redistributed within the fallout pattern from the point of original deposition. The amount is dependent on vegetative cover of the area. Fallout particles 44 to 88 microns in diameter contributed an average of 9.7 percent of the total redistributed radioactive fallout debris following the Priscilla (balloon) detonation as compared to 21 percent following the Smoky (tower) detonation. Particles less than 44 microns in diameter contributed an average of 85.8 percent of the beta radioactivity deposited from the Priscilla detonation as compared to 68.3 percent from the Smoky detonation.

2. Sr^{90} Distribution in Soils of the Environs of NTS: The Sr^{90} levels of the surface (0 to 1 inch) soil samples collected in Nevada and Utah in August, 1958, ranged from 32 to 142 mc/mi^2 in virgin areas near midlines of documented fallout patterns and from 7.5 to 22.7 mc/mi^2 in agricultural areas which did not necessarily coincide with fallout midlines.

The Sr^{90} contamination level in 0 to 1 inch surfaces of cultivated soil samples was lower than levels in virgin area samples probably because of both the reduced

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*The theoretical potential Sr^{89} and Sr^{90} fallout is based on the production of one gram or 27,700 curies of Sr^{89} and 1.14 gram or 146 curies of Sr^{90} per kiloton yield.

contamination by fallout debris due to the distance from maximum deposition along the fallout pattern and the subsequent cultivation of the soil. The observed Sr^{90} levels in agricultural area samples were similar to those reported for other agricultural areas of the country.

The assumption that NTS activities represent the major source of Sr^{90} contamination in the virgin area locations is supported by Sr^{90} percentages of total beta activity. The calculated theoretical percentages of Sr^{90} for various Testing Series tended to be approached by the observed percentages.

Soil from various sampling sites was subjected to a comparative study of Sr^{90} contamination. The amount of Sr^{90} was measured by total solubilization following alkali fusion and leaching with 6 $\underline{N}$ HCl. The results clearly indicate that in the Nevada-Utah area the location of a sampling site in the fallout pattern and the total solubilization of soil samples are necessary in order to evaluate more accurately the area contamination.

The amounts of Sr^{90} leached by 6 $\underline{N}$ HCl varied from 13 to 72 percent of the total Sr^{90} present There was little agreement between available data on dose rates or distance from ground zero to that of total Sr^{90} in the soil.

There were significant differences in distribution of fallout material in soil collected from individual farms within patterns. These differences were closely related to the variety and density of crop whether the radioactivity was measured in terms of gamma dose rate of the location, beta activity per unit area, or as millicuries Sr^{90}/mi^2.

3. Fallout Contamination of Forage Plants: It was again confirmed that the principal source of radioactive contamination on native plants was from fallout particles less than 44 microns in diameter, i. e., vegetation within fallout patterns out to 300 miles from NTS was a "selective" particulate collector. The number of fallout particles retained by the foliage depended upon surface characteristics of the foliage, such as hairs, glands, and other mechanical traps of the plant. As much as 21.6 percent of the radioactive contamination retained by plant foliage during the period from D + 3 to D + 20 days was soluble in 0.1 $\underline{N}$ HCl.

Following both Shots Priscilla and Smoky, the fallout debris contamination of native plant material persisted through the 18 day period. The only measurable change was that due to radioactive decay.

Beyond 200 miles from ground zero, agricultural crops retained less than 15 percent of the fallout from Shot Smoky.

A very small fraction of the total contamination of the soil by fallout debris from tower mounted detonations was accumulated through the root systems of native forage plants (within 300 miles of NTS).

4. Radionuclide Accumulation by Native Rodents: During the Teapot Series (1955), the concentration of radioiodine in the thyroids of rabbits and other native

rodents was found to be a function of distance from ground zero. The maximum concentrations that were measured at approximately 60 miles from ground zero were from two to seven times higher than those measured at 20 or at 160 miles

During this series, between 82 and 87 percent of the total radioactivity found in the thyroid tissue of the native rodents at H + 72 hours was radioiodine. Of this amount, 17 to 20 percent was I^{131} and 65 to 67 percent was I^{133}. The maximum accumulation occurred at approximately D + 14 days, samples taken at D + 20 days contained only I^{131}

Of the several radionuclides ($Sr^{89, 90}$, Y^{91}, Ce^{141} + $Ce\text{-}Pr^{144}$, $Cs^{136, 137}$, and Ba^{140}) accumulated in rabbit bone, 16 to 45 percent was accounted for as Ba^{140} and Sr^{89} In Boltzmann samples, both Ba^{140} and $Sr^{89, 90}$ reached maximum concentrations in bone at 78 to 79 miles from ground zero (fallout time-of- arrival: H + 3.7 hours). For Priscilla samples, Ba^{140} and $Sr^{89, 90}$ maximum values occurred at 129 miles from ground zero (fallout time of arrival: H + 7.1 hours) In Smoky samples, these radionuclides decreased in concentration in bone with distance from around zero However, the concentrations of Ba^{140} and $Sr^{89, 90}$ were nearly the same in bone samples from Priscilla and Smoky jackrabbits collected from areas that had a fallout time-of-arrival later than H + 3 hours

The rate of decay of radioactivity in skin, G.I. tract and contents, and muscle tissue samples collected in the field at the beginning of any particular study and the decline of the radioactivity in these tissues serially sampled from the field population was similar to the rate of radioactive decay of fallout debris. Liver tissue radioactivity levels deviated markedly from the rate of radioactive decay of fallout debris. These relationships were not apparent for bone, which reflected the build-up and retention of specific isotopes.

The radioelement content of jackrabbit bone tissue was studied as a function of time of collection after fallout had occurred. Ba^{140}, Sr^{89}, and Y^{91} concentrations increased with time after fallout to D + 20 days. These radionuclides also were predominant contributors to the beta activity present in the bone. The presence of relatively high levels of Y^{91} was of interest, this radionuclide is the daughter of the short lived Sr^{91}.

Effects of chronic exposure of native animals in fallout patterns upon the radiostrontium content in bone tissue have been investigated. Twelve months after the Upshot-Knothole Series (1955), the accumulated $Sr^{89, 90}$ was found to be a function of distance from the point of detonation. Maximum concentrations in rabbit bones occurred at 130 miles from ground zero (estimated fallout time of arrival: H + 3.5 hours) within previously delineated fallout patterns.

In rabbits collected along Plumbbob fallout patterns approximately 12 months post-series, bone Sr^{90} concentrations correlated poorly with soil Sr^{90} levels. In areas where surface soil Sr^{90} levels ranged from 13.8 to 142 mc Sr^{90}/mi^2, the Sr^{90} bone contents ranged from 10 to 22 pc Sr^{90}/gm Ca with some of the lowest bone contents coinciding with high levels of soil contamination.

In an area included in the Smoky persistence studies (Station VI) jackrabbit bone levels of Sr^{90} were about the same in 1958 as in 1957. There was an increase reflected in 1959, followed by a decrease to 1957-58 levels in 1960, and an abrupt drop in 1961, i.e. from 25 to 10 pc Sr^{90}/gm Ca. This occurred despite the apparent constant level of Sr^{90} soil environment (about 130 mc/mi^2).

Data suggest that the higher levels of Sr^{90} in the indigenous animals are associated with animals that were living in the early sequence of contamination, i.e. during and immediately after fallout, rather than with animals that were born later and merely lived in the contaminated environment.

5. Sr^{90} in Milk Produced in the Environs of NTS: Milk samples collected from Nevada and Utah farms before, during, and immediately after this test series generally reflected an increase in Sr^{90} immediately following deposition from the Plumbbob detonations. A reduction in Sr^{90} in milk occurred with increased time after contamination. The Sr^{90} in milk was a function of the cows' uptake of Sr^{90} but the relationship was not linear with dietary Sr^{90}, or stable calcium and strontium. Data suggest that increases in Sr^{90} levels of milk produced on such farms could be minimized by immediate reduction of pasture grass consumption following contamination. The substitution for a period of several months of fields that were outside the fallout pattern would reduce the Sr^{90} in milk to as little as one-third the levels otherwise present.

APPENDIX A

PROCEDURE

APPENDIX A

PROCEDURE

A.1 OPERATIONS

During Operation Plumbbob, the number of sampling stations and study areas was increased over those provided during previous test series and included distances up to 300 miles from ground zero along the direction of the predicted fallout patterns. While as many as nine "arcs" of fallout sampling stations were established across certain patterns, the specific number used for a particular shot was dependent on (1) the wind direction and speed, (2) the number of accessible trails and roads (which made up the "arcs"), and (3) the number of trained personnel familiar with the specific areas and field operations. There were three nearly complete changes in field personnel during the period of May 1 to September 15 due to the delay of certain shots which Program 37 had selected for documentation.

A.1.1 Shot Participation

Participation of Projects 37.2a and 37.2 was limited to eleven detonations of nuclear devices of a predicted yield of more than 5 kt four mounted on balloons and seven mounted on towers. In addition, an invitation from LRL through CETO was accepted to sample possible venting of radioactive debris from Shot Rainier, an underground detonation. Special emphasis was placed on studies of fallout distribution and characteristics of fallout from Shots Boltzmann, Hood, Priscilla, and Smoky because of their characteristics of yield, type of device support, the amount of shielding and other material in the proximity of the device, etc.

Participation of Projects 37.1 and 37.6 was involved in continuous documentation of selected areas with respect to the fate and persistence of deposited fallout during the D + 3 to D + 21 day period for Shots Priscilla and Smoky. In addition, samples of soil and biological materials were collected and analyzed from several locations in each of the fallout patterns of Shots Boltzmann, Diablo, and Shasta.

The participation of Project 37.3 was limited by a dose rate requirement of at least 2 mr/hr deposited on agricultural areas. This criterion was met at one farm in the fallout pattern from Shot Priscilla and at three farms in the Smoky fallout pattern.

Table 1.1, Chapter 1, shows the project participation according to the selected shots.

A.1.2 Operational Plan

Operational plans, particularly for Project 37.2a, were governed by two major factors (1) the time at which forecasts of wind direction and speed were available to predict the direction of fallout patterns and to estimate the time of fallout arrival at several locations along the pattern and (2) the average magnitude of change in wind direction during a 24 hour period.

For example, the earliest forecasts were available at 1500 hours, D - 1 day. These were based on the 1100 hour wind observations by the U. S. Weather Bureau National Network of stations and the 1100 hour and 1300 hour wind observations by the local observation stations maintained by the NTS Weather Group of the Test Manager's Organization.

The next revised forecast was available at 2100 hours, D - 1 day, and was based on the 1700 hour National Network observations and the 1700 hour and 2000 hour local observations. The final forecasts and fallout pattern predictions were made intermittently from H - 2 hours to H - 30 minutes based on local observations.

The average magnitude of change in wind direction during a 24 hour period that could be expected during the five months of concern to Program 37 were as follows: May, 40 degrees*; June, 34 degrees; July, 28 degrees; August, 25 degrees; September, 38 degrees. Operational planning and project scheduling attempted to accommodate this climatic characteristic.

The program's activities for fallout studies for a detonation routinely began at 1500 hours on each scheduled D - 1 day and consisted of a review of the weather forecast, of the possible uncertainties in the forecast, and of their probable influence on the predicted direction of the fallout pattern. This information was prepared by the NTS Weather Group and FOPU for the formal weather briefings of the Test Manager's Advisory Panel usually scheduled at 1600 hours, D - 1 day. If the Advisory Panel's recommendations were to proceed with the detonation, Project 37.2a teams were assigned rendezvous (standby) locations along the predicted pattern and dispatched from NTS.

In general, five to ten field teams were assigned standby locations near the 20-, 50-, 80-, and 120-mile sampling arcs along the fallout patterns predicted by FOPU. Communications with these teams were maintained by telephone and radio. Specific station assignments were transmitted between H - 3.5 hours and H + 4 hours, depending on the wind speed forecast (fallout time-of-arrival). Each team required 2.5 to 5 hours for the placement of twenty sampling stations and its safe retirement from the area of potential contamination to a standby location. Figure A.1 indicates the roads used for the various sampling arcs.

For the majority of shots, each of the teams assigned to the three to five arcs closest to ground zero, established twenty sampling stations consisting of one granular collector (GC) tray each. In addition, four of the stations had fallout time-of-arrival detectors (TOAD's) and four stations had portable recording area monitors (PRAM's). This equipment is described in Section A.2.2 and A.2.3.

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*These data were based on an analysis of observations made by the Weather Group, NTS, and presented at the pre-Plumbbob FOPU conference at Albuquerque, New Mexico, October 1956.

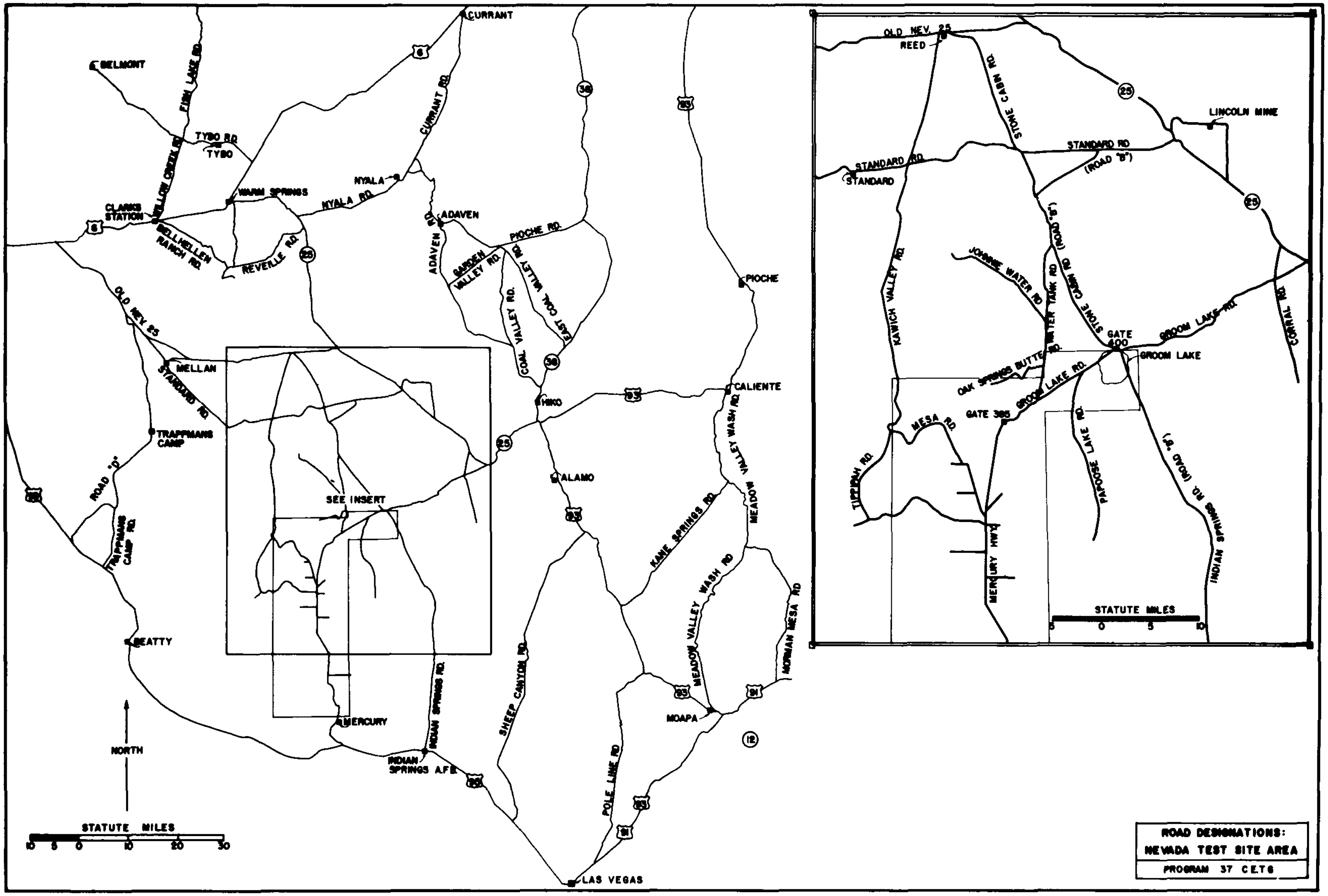

Figure A.1 Roads and Their Designations used for Sampling Arcs in the Environs of the Nevada Test Site.

The teams assigned to arcs at distances greater than 80 to 100 miles from ground zero established identical stations, except that two GC trays were set up at each station. This increased the capability of collecting larger quantities of the less than 44 micron size fallout particles predominantly found at such distances.

Additional studies were made on four shots to compare the relative collecting efficiencies of the soil surface, the GC trays, the resin plates (RPC), and the gummed-paper fallout collectors (GPC) at stations on arcs closest to ground zero. At those stations where TOAD's and PRAM's were located, twelve GPC's also were set up. In addition, on one shot, twelve RPC's were set up at each of the TOAD and PRAM stations that also had GPC's.

On two shots, duplicate GPC's were exposed at the PRAM stations on the first three arcs to obtain fallout material for early beta and gamma decay studies. These GPC samples were recovered by special teams at approximately H + 5 hours and immediately returned to the Mercury Laboratory at NTS for decay measurements.

Descriptions of the various types of fallout collectors are included in Section A.2.4.

Fallout samples were transported to the Mercury Laboratory at NTS by Project 37.2a recovery teams; laboratory processing generally began at H + 30 hours. A preliminary summary of data usually was available for review by D + 7 days after each detonation.

From 0500 to 1200 hours on D + 1 day, the USGS team began the aerial radiometric survey of the fallout patterns out to distances corresponding to fallout time-of-arrival of H + 12 hours or more. During this same time of day, Project 37.2a field teams conducted radiological surveys along their respective arcs across the fallout pattern and recovered samples from the collector stations. If detailed surveys of hot spots were indicated by these initial aerial and ground surveys, two aerial survey teams from the Raw Materials Division, USAEC, began to further document these anomalies at 0500 hours on D + 2 days.

Project 37.1 personnel were assigned to biological and persistence study areas by program officers in the fallout patterns from Shots Priscilla and Smoky by 2000 hours on D + 2 days. The sample collections assigned to each of these teams were started at 1600 hours on D + 3 days. The radiological characteristics of these areas were initially documented by the teams of Project 37.2a.

Biological samples were relayed by courier from the study areas to the Las Vegas Airport and shipped air freight to the UCLA Laboratory. Processing and analysis of these samples began the same day they were received.

A.2 FIELD PROCEDURES AND INSTRUMENTATION

A.2.1 Delineation of Fallout Patterns by Ground and Aerial Radiometric Surveys

Delineation of the various radioactive fallout fields, requiring a cooperative effort of eight to ten ground survey teams and the USGS aerial radiometric survey unit, started during the D + 1 day recovery of collector stations and samples. At this time the field teams measured the residual dose rates of fallout by monitoring their assigned sampling arcs and adjacent roads while the aircraft flew flight patterns designed to determine the extent of the fallout pattern.

All ground measurements were made in undisturbed areas and approximately 3 feet above the ground surface at least 20 feet from the vehicle. In general, the arcs were monitored at 5 mile intervals until an intensity of 1 mr/hr was located. The intervals between measurements were then reduced to 0.5 mile until an intensity of 1 mr/hr was found on the opposite side of the pattern. From these data the monitoring teams estimated the location of maximum intensity on their respective arcs, then resurveyed the arc 1 mile on each side of this location of maximum intensity at 0.2 mile intervals. The locations of all monitoring and sampling stations were determined with reference to established trails and roads by corrected vehicle odometer readings. Corrections were necessary since the vehicle odometers read from 80 to 130 percent of the correct mileage as determined by the measured five mile course on Mercury Highway at NTS.

A.2.1.1 Ground Survey

Ground surveys were accomplished using Office of Civil Defense Mobilization type CD-V-700 beta-gamma survey meters, as manufactured by Victoreen Instruments Company and Nuclear Measurements Corporation, or CD-V-710 Model 4, ionization survey meters produced by Jordan Electronics, Incorporated. These instruments were available in the required numbers whereas other types or kinds were not. Each instrument used was calibrated using the Rad-Safe 534 mc Co^{60} source, located at the NTS control point. Also, a 10 mg radium source was used for the calibration of Geiger Mueller (GM) type (low range) instruments. See Appendix B for an evaluation of these survey meters.

Based upon the recommendation of the Test Manager's "Committee to Establish Fallout Doses and Intensities", (Conference, December 1957, NTS), all survey instrument readings were normalized to the U. S. Radiac T1-B (AN/PDR-39). Although errors of from 10 to 20 percent in Radiac survey readings have been reported by various investigators (References 1 and 2), it was assumed that normalization to a common instrument would minimize the errors arising from differences in instrument radiation sensitivity. The conversion factors, based upon comparative measurements obtained by personnel of Program 37 in fallout radiation fields and previously published data (References 3 and 4) are summarized in Table A.1.

Since survey meter readings were made at different time after H hour, readings were corrected for decay to a common time of H + 12 hours. On the basis of gamma decay rate studies (Chapter 4) it was found that the $T^{-1.2}$ decay rate did not hold for the early decay period. Also the decay rate slopes varied with the age of the fallout material. Table A.2 lists the factors used to correct any given gamma intensity to H + 12 hour intensities for time intervals up to H + 50 hours based on composite decay curve, Figure 4.11.

TABLE A.1 Conversion Factors for Various Types of Survey Meters[a]

Instrument	Detector Type	Conversion Factor
OCDM Type CD-V-710, Model 4	Ionization chamber	1.0
OCDM Type CD-V-700	GM (shielded)	1.5
Beckman Model MX-5	GM (shielded)	1.3
Nuclear Model 2610A	GM (shielded)	1.9

[a] Used by Program 37 to normalize gamma dose rates to equivalent radiac T1-B dose rates.

TABLE A.2 Factor to Convert Observed Gamma Intensities to H + 12 Hour Intensities Based on Composite Decay Curve, Figure 4.11

Time of Reading, H + hrs	Conversion Factor	Time of Reading, H + hrs	Conversion Factor	Time of Reading, H + hrs	Conversion Factor
0.8	0.021	6.5	0.523	26	1.856
0.9	0.026	7.0	0.567	27	1.913
1.0	0.033	7.5	0.609	28	1.975
1.2	0.049	8.0	0.653	29	2.032
1.4	0.070	8.5	0.693	30	2.094
1.6	0.093	9.0	0.740	31	2.127
1.8	0.119	9.5	0.782	32	2.197
2.0	0.148	10.0	0.828	33	2.272
2.2	0.156	10.5	0.867	34	2.352
2.4	0.165	11.0	0.909	35	2.439
2.6	0.174	11.5	0.956	36	2.469
2.8	0.184	12.0	1.000	37	2.531
3.0	0.195	13	1.088	38	2.597
3.2	0.210	14	1.156	39	2.667
3.4	0.228	15	1.219	40	2.739
3.6	0.246	16	1.275	41	2.778
3.8	0.264	17	1.343	42	2.857
4.0	0.284	18	1.405	43	2.941
4.2	0.301	19	1.460	44	2.985
4.4	0.319	20	1.520	45	3.030
4.6	0.339	21	1.585	46	3.125
4.8	0.358	22	1.642	47	3.174
5.0	0.380	23	1.697	48	3.255
5.5	0.427	24	1.761	49	3.278
6.0	0.483	25	1.801	50	3.333

A.2.1.2 Aerial Radiometric Survey

Using the available information regarding the fallout pattern from project field teams, and Off-Site Rad-Safe teams, including a postshot analysis from FOPU of the weather observations and an estimate of the cloud trajectory and midline out to 500 miles from ground zero, the USGS aerial radiometric survey team made a D + 1 day aerial survey of the area. A serpentine pattern was flown along the bearing of the estimated midline out to distances corresponding to fallout times of H + 12 to H + 16 hours. Continuous radiation intensity readings (counts/sec) were taken by recording gamma radiation monitoring equipment.

The flight patterns were, in actuality, a series of straight line bearings over predetermined visual reference points across terrain as level as practicable. The initial flight line was begun before the edge of the fallout pattern was reached, crossed the fallout pattern at approximately right angles, and continued past the opposite boundary of the pattern. A series of such tranverses at increasing distances from ground zero provided data from which the areas of fallout contamination were delineated. The direction of traverses was often controlled by roads in order to maintain the accuracy of the plot. In the absence of cultural features, dead-reckoning navigation was employed with reasonable accuracy for distances up to ten miles under calm atmospheric conditions.

An air speed of 140 ±20 mph was maintained at an altitude of 500 ±25 feet above ground level using a DC-3 aircraft. A position plot was maintained by an observer, utilizing a view finder, who marked the position of the aircraft on a map and at the same time actuated a marking system over recognized visual reference points. The marking system placed fiducial marks on all record tapes and camera film. The flight pattern was also recorded by a 35-mm, gyro stabilized, continuous strip-film camera.

The radiometric survey system used has been described in detail by the designers, Davis and Reinhardt (References 5, 6, 7). The detectors consisted of a battery of five thallium-activated NaI crystals, 4 inches in diameter and 1 inch thick, and one crystal, 1.5 inches in diameter and 1 inch thick. These crystals were used interchangeably, depending upon the required counting rate. A positive high voltage supply was used to feed the photomultiplier tubes (No. 6364) operating at approximately 1500 volts. The signal from the photomultipliers was fed through a mixing preamplifier, amplifier, discriminator-rate meter, and vacuum tube voltmeter, which recorded the counting rate on Esterline-Angus recorders.

The rate meter was calibrated periodically throughout the flight by a Frahm resonant-reed controlled oscillator giving a pulse frequency of 500.2 cycles/sec. Since the equipment had to operate over a wide temperature range, a calibration procedure utilizing a Cs^{137} source was used. The discriminator was set at the energy level of the Cs^{137}, and, after the source was placed in position under the crystals, the amplifier was adjusted to a predetermined value above background.

Calibration for the nonlinearity of the equipment was obtained by using radium sources of various intensities placed at a distance of 124 cm from the bottom of the array of crystal-photomultiplier cans. An instrument lag ranging from 400 to 750 feet, depending on the time constant, was not considered in preparing the corrected values because of the scale of the maps used (1:500,000 or approximately 8 miles to the inch). The internal accuracy of this system was estimated by the USGS team to be ±5 percent.

Conversion of aerial records, expressed as counts/sec, to mr/hr at 3 feet above ground surface was accomplished by concurrent monitoring of roads by both ground and aerial survey teams following several of the Plumbbob shots, usually on D + 1 day. Since the mixed fission product fallout field resulted in multienergy radiation, the author believed that an empirically derived conversion factor would be more valid than other derived expressions.

Using corrected road mileage for ground survey locations and the recorded aerial reference points, it was possible to obtain gamma intensity readings for the same location on the ground by both methods of measurement. Using the most reliable ground survey data and aerial data, it was determined that 1 mr/hr at 3 feet was equivalent to aerial readings of 50,200 counts/sec ± 10 percent for Boltzmann; 48,500 counts/sec ±12 percent for Hood and 50,300 counts/sec ± 12 percent for Smoky locations. On the basis of these values, a mean conversion factor of 50,000 counts/sec per mr/hr at 3 feet was used to convert the aerial data to ground intensity values.

After preliminary analysis of the initial aerial and ground surveys and PRAM data, further delineation of hot spots was accomplished by ground monitoring teams or two aerial survey teams from the Raw Materials Division, USAEC, consisting of a pilot and an observer. The latter flew aircraft (Super Piper Cub) equipped with Mount Sopris scintillation counters, Model SC129-3, coupled to Welltab recorders. The sensitive elements in these instruments consisted of thallium-activated NaI crystals, 1.5 inches in diameter and 1.25 inches long.

This equipment was calibrated with a 50 mc radium source. Also, it was tested in flight over a calibrated source at Grand Junction, Colorado. Reproducible readings were obtained throughout a range of conditions in spite of the relative sensitivity of the radiation detectors to air turbulence.

Surveying with the Super Piper Cub aircraft usually began 50 feet above the terrain. If radiation produced off-scale readings on the scintillator, the altitude was increased in increments of 100 feet until on-scale readings were obtained. Ground elevation in a particular area was established by a series of low passes made a few feet above the ground. During the survey flight, altitudes were controlled by the pilot and his altimeter observations. Air speeds varied between 60 and 120 mph, but were usually maintained at 110 mph.

The hot spots usually were delineated by describing a grid consisting of two sets of flight lines at right angles to each other. The flight patterns over the selected areas were, however, strongly influenced by topography. It was generally desirable to maintain traverses as straight as possible, since this facilitated the plotting of data. Therefore, whenever feasible, flight lines were over the terrain of least relief.

Data analyses and the plotting of isopleths of dose rate were done at the Mercury Laboratory.

A.2.2 Measurement of Fallout Time-of-Arrival

Records of fallout arrival were obtained by forty PRAM units, described in Section A.2.3, and forty TOAD's located at assigned stations on various sampling arcs before the predicted time of fallout at each arc along the predicted pattern. The PRAM's provided records of dose rate during and immediately after fallout up to the time of recovery. A rise of 2 mr/hr over background radiation levels was taken as the time-of-arrival of fallout or radiation at that location.

The TOAD's were self-contained units developed at AEP/UCLA (Reference 8). These units consisted of a conventional surveymeter circuit having a Geiger tube of 100 mg/cm^2 wall thickness and a one-shot multivibrator which operated a meter which indicated the radiation level. An electric clock in the instrument stopped when the radiation level reached the selected point, 2 mr/hr above background, providing a record of the time-of-arrival of radiation.

A.2.3 Measurement of Radiation Intensity During and After Fallout

The PRAM's placed at selected locations for each shot provided a record of dose rate over the period of time before, during, and after fallout until station recovery. Integration of intensity versus time curves allowed a comparison of measured dosages with estimated dosages derived from individual intensity-measurement extrapolations. These data also provided a means for determining radiation decay values in the field at selected points within the pattern.

This equipment (Jordan Electronics, Inc., PRAM Model 6) consisted of Neher-White logarithmic-response ionization chambers coupled to Esterline-Angus Model AW graphic recorders through battery-operated dc amplifiers. These components were packaged in a 16 x 13 x 16 inch, shock mounted, dust proof field case. The detector unit (ionization chamber) was suspended 3 feet above the ground and connected by cable to the recorder, 15 to 20 feet distant, to eliminate the possible shielding effects of the recorder case. Three detection ranges were utilized: 0.1 to 100 mr/hr; 1 to 1000 mr/hr; and 0.01 to 10 r/hr. A continuous record of gamma-radiation intensity at selected GC stations throughout the pattern was thus provided within a time period of H + 30 hours.

A.2.4 Collection of Samples of Fallout Debris for Determination of Activity per Unit Area

The microcurie per square foot values for deposited fallout debris were determined from samples collected by GC and from soil samples when necessary. The GC was developed by the UCLA Laboratory and was the primary collector utilized by this Program (Reference 9).

Granular collectors consisted essentially of cylindrical polyethylene pellets, 0.25 inch long and 0.125 inch in diameter. The pellets were spread uniformly over two mylar sheets placed side by side on a 29 x 43 x 0.5 inch deep metal tray which was center-divided to provide two samples per tray. Each duplicate sample had a collecting surface area of 4.73 sq ft (Figure A.2) The samples of fallout material collected on these trays were not subjected to previous contamination as was the case for soil samples, yet the pellet covered tray did provide a collecting surface similar to that of soil. These tray samples were used for many different kinds of measurements that had not been possible during previous test operations.

Figure A.2 Field Preparation of Granular Fallout Collector (GC).

One hundred to 300 trays, GC collectors, were exposed on each above surface shot studied and were set up before predicted fallout arrival for collection of fallout material deposited at ground level. The exposed pellets were recovered in bags formed by binding the edges of the mylar sheets together with wire. These bagged samples were than placed in Kraft paper bags, labeled, and transported to the Mercury Laboratory on D + 1 day. The fallout material collected was separated from the pellets and assayed at the Mercury Laboratory (See Section A.3.1).

On each of four shots, selected sampling stations on certain arcs were equipped with GP collectors with the addition, on one shot, of RPC's to permit a comparison of the efficiency of the several types of fallout collectors used by various organizations.

The RPC's were galvanized iron plates (4 by 9 inches) on which a nondrying alkyl resin solution was applied after the plates were mounted in field positions. The resin solution was composed of 66.7 volume percent toluene, 1.3 volume percent tributyl phosphate, and 32.0 volume percent resin (DuPont RL-233). Evaporation of the tolune left a residue which remained tacky throughout the exposure and assay periods.

Resin plates were mounted by C-clamps onto a 2 by 2 inch wooden bar, 5.5 feet long. Two posts supported this bar 3 feet above the ground, allowing exposure of the plates in a horizontal position. Cross contamination of the samples was prevented by transporting the exposed plates in slotted, dustproof boxes. Radioassay procedures are described in Section A.3.1.2.

Gummed paper collectors were Avery Adhesive Label Corporation No. 3 gummed papers taped onto 9.5 by 10.5 inch galvanized iron plates. A collecting surface area of 0.5 sq ft was thus provided. Field mountings and radioassay procedures were identical to those used for the RPC, and the entrapped particles were retained on the collectors by folding the papers into 4 by 9 inch halves.

All collectors were set up in the field prior to the predicted arrival of fallout and were exposed until D + 1 day. Exposed samples were returned to the Mercury Laboratory for processing and assay to determine activity per unit area at H + 12 hours. These values were compared to activity per unit area obtained from surface soil samples collected by removing soil to a depth of 1 inch from a 1 sq ft template. Soil samples were collected from stations at which the GC tray, RPC's, and GP collectors were exposed.

A.2.5 Instrumentation and Sample Collection in Persistence Study Areas

With the combined efforts of Projects 37.1, 37.2, and 37.6, a cooperative study was undertaken to determine the physical and biological persistence of fallout deposited at various locations within the pattern. The areas of study, selected on the basis of contamination level, accessibility, and characteristics of the flora and fauna, were established on the midline of the fallout pattern at or near locations of the Project

37.2a sampling arcs. They were spaced to provide study sites between 50 and 200 miles from ground zero according to the characteristics of the fallout pattern under study. Any other biological sampling within any particular fallout pattern was identified with respect to the midline and the distance of the sampling site from ground zero and the time of fallout.

The layout of a typical persistence study area is diagramed in Figure 6.1, Chapter 6. Along the Priscilla pattern, four such stations were established between 68 and 197 miles from ground zero. Similarly, stations were established at 99 and at 136 miles from ground zero for the Smoky pattern. These detonations were chosen for detailed comparison on the basis of similarity in yield and height of burst and difference in support of the nuclear devices. The stations were established on D + 3 days and maintained continuously to D + 21 days. See Figures 2.3 and 2.7, Chapter 2, for specific locations.

The extent and nature of the fallout contamination was determined during the period of D day to D + 2 days by Projects 37.2 and 37.2a. Animal collection areas 4 miles long (along the midline) and 1 mile wide (across the midline) were delineated by radiation intensity readings taken at 100 yard intervals along both axes with GM survey meters (Nuclear Instrument and Chemical Corporation, Model 2610A). Each station was located within the animal collecting area and was documented as follows:

(a) Five GC units were changed at 24 hour intervals during the 18-day sampling period to determine the amount of redistribution of originally deposited fallout, latent secondary fallout, and/or additional fallout contamination due to subsequent detonations.

(b) One automatic air sampling unit was operated continuously on 6-hour sampling intervals over the 18 day period to measure the concentration of radioactive airborne particles due to any of the above listed parameters. These sampling units, similar to those used during the Teapot Test Series (Reference 10), consisted of: (1) a positive displacement pump powered by a 0.5 hp ac motor; (2) a timing mechanism that permitted selection of the starting time and the duration of sampling; and (3) an indexing motor that advanced the sample holder in the magazine. The same holder held eight, 3.37 inch diameter Whatman No. 41 filter papers supported by Mine Safety Appliance Company all-purpose dust pads, type BM-2133. The average air-flow rate, as determined periodically over a 2 day sampling period at the field locations, was 13.9 ft^3 per minute.

The units were placed on swivel mounted tables and were equipped with wind vanes to maintain the sampling orifice in a windward direction. Filters from each magazine were placed in individual plastic boxes for return to the laboratory from the field. Air sampling at all stations was initiated at 0400, 1000, 16000, and 2200 hours to permit an evaluation of the influence of daily temperature and air movement upon radioactive aerosol concentrations. In addition, this schedule of sampling permitted a comparison of samples collected at different stations by eliminating variations due to time of sampling.

Individual exposed filters from the air samplers were assayed for beta activity using a large window (4 by 9 inches) gas-flow counter using appropriate Sr^{90} - Y^{90} reference standards. See Section A.3.1.2 for details of this equipment. Samples were assayed not earlier than 96 hours after completion of the sampling interval to allow radon-thoron decay products to reach a relatively low and constant level of activity.

The activity values determined for each filter were corrected to an average air concentration per sample by a factor derived from the midtime of sampling interval and average flow rate.

(c) One PRAM was set up and maintained. Its detector was mounted 6 inches above the ground surface to provide a continuous record of gamma activity levels in the area of biotic interest. Also, this record provided a comparison of decay of radiation in the field to the decay of the initial (D + 1 day) soil and fallout collector samples measured in the laboratory.

(d) Survey-meter readings were taken daily to document changes in radiation intensity. Particular emphasis was placed upon documenting the concentration of fallout in micro-environments adjacent to shrubs and in small depressions of the soil surface.

(e) Two recording anemometers, one at 0.5 foot and the other at 3 feet above the soil surface, were maintained at Stations I, III and V following Shot Priscilla and Stations VI and VII following Shot Smoky, to provide measurements of wind speed and direction that could be useful for the interpretation of data relating to the redistribution of fallout. These anemometers were calibrated and furnished by the NTS Weather Group. In addition, a recording hygrothermograph was maintained in a suitable shelter on the soil surface. A rain gauge, consisting of a 10 inch polyethylene funnel mounted over a half gallon polyethylene bottle, was maintained to measure precipitation.

(f) Soil samples were collected and processed as described in Section A.3.1.3 from areas representative of animal environments and at intervals corresponding to the times of collection of local fauna specimens by Project 37.1. The 135 foot-square grid shown in Figure 6.1 provided 16 specific locations where soil samples were also taken at the beginning (D + 3 days) and end (D + 20 days) of a persistence study period. Five surface soils were taken from the periphery of the grid on D + 5, D + 9, and D + 13 days. Soil profiles were taken, in increments of 1 inch, to a depth of 4 inches from four locations at the beginning and end of the study.

(g) Native rodents (principally Dipodomys sp.) and jackrabbits (Lepus californicus) were collected on D + 3, D + 5, D + 9, D + 13, and D + 20 days. The rodents were collected in treadle-type metal box traps; the jackrabbits were shot with .22 caliber rifles (Reference 11). All animals collected were packaged with dry-ice for shipment to the UCLA Laboratory where the radioanalysis was performed (Section A.3.6.3).

The rate of animal sampling was adjusted to assure population survival within the study area during the 18 day period. Thus a maximum of 5 rabbits and 5 rodents was taken at any one sampling period even though, in some cases, more animals were available.

(h) Bulk plant material was collected at times corresponding to those for animal sampling. These samples were forwarded to the UCLA Laboratory where the sample processing and radioanalysis was done (Section A.3.6.3). Data from these samples provided values for activity per unit weight of plant material to document the degree and persistence of range forage contamination.

(i) Two types of film pack dosimeters were exposed during the persistence study, one a standard personnel badge and the other an experimental thin window dosimeter designed to determine beta-ray dose immediately below the cornified epithelium of the skin (Reference 12). Sets of both kinds of film badges were placed in various microenvironments in open areas mounted on a post at 1 inch, 1.5 feet, and 3 feet above the soil surface. Badges also were placed within the top foliage of a shrub and at its base. The badges were serially exposed to provide estimates of beta versus gamma dose for the seven periods of D + 3 to D + 5 days, D + 3 to D + 7 days, D + 3 to D + 10 days, D + 3 to D + 13 days, D + 3 to D + 20 days, D + 5 to D + 20 days, and D + 10 to D + 20 days. The film badges were prepared and processed by the Health Physics Section, AEP/UCLA as described in WT-1178A (Reference 12).

Items (d), (f), (g), and (h) above, apply as well to other sample collections made laterally to the midline during persistence studies and during project participation on other detonations.

A.2.6 Determination of Biotic Availability of Fallout in Agricultural Systems

This study (Project 37.3) was dependent upon fallout patterns crossing areas of agricultural significance. The levels of radioactive contamination determined the duration of these studies. Two mr/hr at H + 12 hours was the minimum acceptable dose rate. When feasible, farms were selected near Project 37.1 study areas or Project 37.2a station locations.

A.2.6.1 Selection of Agricultural Study Areas

Twelve areas were sampled pre-Plumbbob on the basis of their geographic location around NTS. Each area was located within three miles of a U. S. Public Health Service surveillance station. Five of the farms selected had been documented after the Teapot Series due to their proximity to midlines of respective fallout patterns. Dairies were operating on seven of the ten farms selected. In addition, two noncultivated areas were included in the pre-Plumbbob background study.

Samples of soils, forage crops, hay, dairy feeds, cattle feces, and milk were collected at Milford and St. George, Utah; Mesquite, Alamo, Pahrump, and Lund, Nevada; and Bishop, California. Additional soil samples were obtained at Cedar City, Beaver, Beryl Junction, and Caliente, Utah; Overton, Tempiute, and Eureka, Nevada; and Barstow, California. Additional specimens were obtained from the grazing areas of the University of Nevada experimental cattle herds near Caliente and Knoll Creek, Nevada. Radioassays on these samples provided background information on the availability of selected fission products in agricultural environments due to previous nuclear tests. To establish a comparative set of data, the above areas were resampled after the completion of Operation Plumbbob.

During the test series, five agricultural areas contaminated by fallout debris from Shots Priscilla and Smoky were documented as follows:

(a) Surface soil, growing feed stuffs, pasture forage, and cattle feces and milk derived from these sources were serially sampled until the end of Plumbbob and analyzed to determine the presence, distribution, and persistence of Sr^{90} and Cs^{137} in the various components of the farm environment.

(b) Analysis of the above serial samples yielded data indicative of any changes or trends in strontium and/or cesium accumulation in cattle. These data were evaluated relative to time of fallout and fallout debris characteristics, as determined by Projects 37.2 and 37.2a.

(c) Fallout debris characteristics were evaluated relative to their effects on the redistribution and metabolism of selected fission products, particularly those isotopes metabolized into milk.

A.2.6.2 Documentation of Contaminated Agricultural Study Areas

Based on radiological descriptions of the fallout contaminated areas obtained from Project 37.2a, detailed monitoring was done to select the specific farms for study. The radiological and geographical descriptions of the sampling sites are given in Table 8.2, Chapter 8.

(a) Soil samples were obtained from soil cores taken with augers in the permanent pasture and alfalfa fields sampled in the pre-Plumbbob survey. From cultivated areas, soil cores 3 5/8 inches in diameter and 6 inches deep were collected on a grid pattern of 3 feet between core centers. Twenty cores were composited for each sample. Soil cores from the two native areas were 3.5 inches in diameter and 2 inches deep. The same sampling sites were used for post-Plumbbob sampling.

Soil samples from or near sampling areas used by the UCLA Laboratory in earlier surveys (1952-1956) were collected in 1 inch increments from 1 sq ft areas to a depth of 6 inches. During this test series, triplicate soil profiles were taken from each field sampled, taking care to avoid eroded or overflow areas. The two virgin areas and the Delamar cattle range were sampled in the same way.

Soil samples also were collected using 0.25 sq ft metal templates to a 6 inch depth in 1 inch increments from the fields studied in the Smoky and Priscilla fallout patterns. The numbers of replicate profiles per field are given in the tables of Chapter 8. To prevent cross contamination, all soil sample containers were sealed in the field of origin. Each depth increment of each profile was packaged separately.

(b) Plant material was collected from fields in fallout patterns to determine the relative retention of fallout by plants and the amount of radioactivity consumed by cattle. The area unit was 1 square yard enclosed by a portable, steel template and the area harvested per sample was 2 square yards or more. Five pounds (wet weight) or more of plant material was collected per sample. Pasture grasses and alfalfa were clipped with hand shears 2 inches above the ground surface. Triplicate, composite samples were harvested from each field after fallout contamination. Hay and ensilage were also sampled when these feeds were included in the cattle's diet.

Dairy feeds were sampled during the feeding period and composite samples were taken to represent the dairy herd diet. These samples included hay, concentrates, silage, and beet pulp. A volumetric fraction of the material fed was collected so that the weight consumed by the dairy herd could be determined from the dry samples. Each sample of plant material was appropriately packaged at the sampling site to avoid cross contamination from other materials during transportation. The samples were air dried at the Nevada Test Site in a room with a filtered air supply and were oven dried at the UCLA Laboratory in a forced draft oven maintained at 70°C for 24 hours. The plant materials were ground by Wiley Mill to pass a 20 mesh screen.

The mean feed consumption at the time of sample collection was checked against longer term averages. Daily hay consumption at Veyo was determined from the number of bales fed daily times the average weight of the bales. The same lot of hay was fed from May through October. At Fremont, loose hay was fed and the weight of the night feeding was determined with scales and compared to the consumption rate from the stacked hay over the past 2 months. Records of hay consumption of Panguitch were obtained from the mean weight of the bales purchased and the number of bales fed over a 2 week period.

Comsumption of dairy concentrates was checked against the weight of commercial deliveries made on a bi-weekly basis at Fremont and Veyo. At Paguitch the concentrates were purchased in 100-pound lots and the rate of use was determined from the frequency of purchases.

Pasture consumption was calculated in terms of the amount of hay fed to maintain milk production when the cattle were not on pasture. Samples of pasture herbage and of hay were dried to a constant weight and dried pasture herbage was assumed equivalent in nutritive content to dried hay of the same plant species. When the pasture was a species different from the hay, total digestible nutrient data were taken from Reference 13 and the dry weight of the hay fed was converted into the weight of pasture herbage needed to maintain milk production levels.

(c) Milk was collected from either the evening or morning milkings. When feasible, milk sampling followed feed sampling 12 to 24 hours. Contaminated feeds were fed to dairy herds at least eight days before milk samples were collected.

Halazone powder was used as a preservative of milk samples which were stored until November. A measured volume was dried and charred under infrared lamps in silica evaporating dishes and ashed 16 hours in an oxygen atmosphere at 400°C in a muffle furnace. The ash was weighed, ground in porcelain mortars, and stored until assayed.

Milk production records were consulted to determine the mean production per cow. At Veyo these were the weight of the most recent deliveries made from a refrigerated storage tank on alternate days. Daily deliveries were made at Fremont, and in addition the production record of individual cows was kept by the farmer. At Panguitch the volume of milk was determined daily by the farmer before delivery to customers.

Composite feces samples were collected in milking parlors or holding pens. These samples were dried 24 hours at 70°C and treated as plant material in processing and radiochemical determinations.

A.2.6.3 Fallout Assessment

The level of radiation from fallout in the farm fields was determined with GM-type survey meters during the selection of study areas. All readings were corrected by the appropriate factors described in Table A.1.

The beta activity of soil and plant material was determined as the difference in levels of beta activity between fallout contaminated samples and that of like material which had not been exposed to fallout from Operation Plumbbob. Radiation background values for soil samples were usually obtained from the deepest subsoil sample collected from a profile. However, in the case of surface soil samples from Veyo after Shot Smoky, the residual beta activity due to contamination from Priscilla fallout was subtracted from these surface soil beta activities at the time of counting. Pre-Plumbbob plant material was used to obtain the background beta activity of plant materials.

Agricultural soils were counted in the flat-plate gas-flow counting chamber described in Section A.3.1.2. Appropriate selfabsorption, backscatter, and decay corrections were made when necessary.

Soils assayed for beta activity were 100 gram samples in 4 by 9 inch cardboard boxes. Ten replicates were counted from core samples and 1 sq ft increments. Six or more replicates were counted from 0.25 sq ft increments.

The beta activity of plant materials was determined, and corrections were made as described in Section A.3.6.3. Radiochemical procedures used for determining the radionuclide contents of samples were those published by the Analytical Branch, Health and Safety Laboratory (HASL) New York Operations Office (Reference 14). Fifty to 75 grams of soil were analyzed as required depending on the level of activity. Determinations of calcium and stable strontium were also made on selected samples.

A duplicate set of the soil cores was set to the U. S. Department of Agriculture for Sr^{90} analysis under the procedures used in Sr^{90} assessment under the world-wide sampling program. The samples were leached with 6 N NCl and the Sr^{90} content was determined at HASL.

Two thousand gram aliquots of the composite soil cores were submitted to Dr. Gustafson, Argonne National Laboratory for Cs^{137} determinations by gamma spectrometry. The same weight of 1 sq ft surface soil sample collected adjacent to the core was also analyzed for Cs^{137}.

A.3 LABORATORY PROCEDURES, INSTRUMENTATION, AND DATA ANALYSIS

A.3.1 Determination of Activity per Unit Area and Particle Size Distribution

A.3.1.1 Removal of Fallout Material from Granular Tray Collectors

The Mylar bags of plastic pellets from the exposed GC trays were returned to the Mercury Laboratory on D + 1 day. The fallout debris was separated by processing these samples as follows. Approximately 500 ml of isopropyl alcohol was introduced into the Mylar bag to wet the pellet matrix The pellets were then emptied onto a 2-mm screen 17 inches in diameter which had been placed in an 18.5 inch immersion pan. The Mylar sheet was spread out and clipped to an upright stainless steel tray mounted over the immersion pan, washed down with isopropyl alcohol under pressure, and finally dried with a rubber squeegee. All particulate matter on the Mylar sheet was thus rinsed into the immersion pan. Up to 3 liters of isopropyl alcohol was used for this phase of the procedure.

The immersion pan, containing approximately 3.5 liters of isopropyl alcohol and the screen bearing the plastic pellets were transferred to a machine, the dunker, designed to alternately immerse and drain the pellet matrix in the alcohol bath thirty times per minute. The details of construction and operation of this apparatus have been published in a separate report (Reference 9).

The machine was operated for 5 minutes and rinsed with approximately 1 liter of fresh isopropyl alcohol under pressure to displace any fallout material still entrapped within the pellet matrix. The immersion pan was drained, and the suspension passed through a 44 micron sieve, 3 inches in diameter. The pan was rinsed and policed with about 250 ml of fresh isopropyl alcohol in 20 to 25 ml aliquots which also passed through the 44 micron sieve. The suspension of less than 44 micron particles was collected in straight-sided 6-liter-capacity Bain-Marie enameled pots.

Following the initial wet sieving, the pellet matrix was rewashed using an additional 4.5 liters of isopropyl alcohol for a second wet sieving period of 5 minutes. This suspension was passed through the greater than 44 micron sieve and collected in a second Bain-Marie pot.

The relative efficiencies of particle removal by first, second, and third wet sieving operations are described in Table A.3. The data indicate that by use of the second washing operation an efficiency of particle removal of approximately 95 percent was obtained.

TABLE A.3 Recovery of Fallout Material Collected by Granular Collector as a Function of Number of Alcohol Washings

Data from duplicate samples from Station No. 0709, Shot Priscilla. Totals based on summation of beta activity of material obtained from three washings.

	Wash No. 1		Wash No. 2		Wash No. 3	
	Activity Total Sample	Activity < 44 micron Fraction	Activity Total Sample	Activity <44 micron Fraction	Activity Total Sample	Activity < 44 micron Fraction
Duplicate No. 1						
μc/sq ft, H + 12 hr	31.2	22.5	2.87	2.79	1.15	1.13
Pct of total activity	88.6	85.2	8.1	10.6	3.3	4.3
Duplicate No. 2						
μc/sq ft, H + 12 hr	25.0	19.6	1.84	1.79	1.20	1.20
Pct of total activity	89.2	86.7	6.6	7.9	4.3	5.3

The suspensions from the above procedure, containing fallout particles less than 44 microns in diameter, were each passed through a membrane filter (Millipore Filter Company, type HA) mounted in a Millipore filter holder. Sufficient rinses were also passed through to ensure removal of all particulate matter from the container as determined by survey meter measurements. The filter was dried by air passage induced by vacuum pump and by a four minute heating under an infrared lamp. The filter and its residue were then transferred to a dustproof plastic culture dish for radioassay.

Selected samples of the above suspension were further fractionated by appropriate sedimentation techniques to yield the less than five micron fraction. This fraction was also assayed.

The material retained by the 44 micron sieve was dried under infrared lamps and quantitatively transferred to a sieve assembly containing a sequence of screens of the following pore sizes: 1000, 500, 350, 297, 250, 210, 177, 149, 105, 88, and 44 microns. After 30 minutes on a Ro-Tap testing sieve shaker, the sieve assembly was removed and dismantled. The individual screens containing specific particle-size fractions were placed in 2-inch diameter plastic culture dishes for radioassay.

A.3.1.2 Assay of Collector Samples

Samples were assayed for beta activity by scintillation probes (Nuclear Chicago, model DS-5) with 2-inch diameter thin anthracene crystals as the detection elements mounted in 2-inch thick lead shields. Outputs from these probes were fed into binary scalers (Nuclear Chicago, Model 183). The minimum energy detectable by the aluminum-covered anthracene crystals was 60 kev. The count acceptance rate was increased to approximately 1.5×10^7 counts/min by introduction of two decade glow tubes (Atomics Instrument Co., Model 180) between the last scaling stage and the mechanical register. Counting efficiencies were determined with Sr^{90} - Y^{90} standards which had the same dimensions and containers as the samples for which they served as standards.

Some series of particle size fractions were weighed to determine the necessity for self-absorption corrections. The quantity of any given fraction, however, was expressed in terms of activity, rather than attempting to relate such activity to weight, per se. Activity per unit area values were determined by correcting from actual surface areas of all fallout collectors to activities representative of an exposed surface on 1 sq ft.

Beta assays of resin-plate, gummed-paper, air- and soil- sample materials, and some particle-size fractions were made using a thin-window, 4 by 9 inch, flat plate beta proportional counter followed by a linear amplifier (CMR-7, Model PA-6) and a binary scaler (CMR-7, Model SC-3B). These units were manufactured in 1953 by the CMR-7 Electrical Section. LASL. The flat plate, methane gas flow counters consisted of aluminized Mylar windows of 0.8 mg/cm^2 thickness and a detection area of 3.5 by 8.0 inches. The mechanical registers of the scaling units were replaced with Sigma Instruments Company Cyclonome pulse counters, Model 9A, to increase the count acceptance rate to a maximum of approximately 7.8×10^6 counts/min. These flat plate, detector units were shielded above with 1 inch of steel plate and on three sides by 3 inches of lead brick.

Sr^{90} - Y^{90} standards, prepared by impregnating 4 x 9 inch filter paper were utilized to correct observed count rate data. All radioassay values were extrapolated to H + 12 hours on the basis of the composite Plumbbob beta decay curve presented in Figure 4.11.

A.3.1.3 Assay of Soil Samples

Soil samples received in the laboratory were dried, if necessary, in flat trays placed in a drying-room environment of filtered circulating air. Samples were dry-sieved through 2-mm screens for 10 minutes on Ro-Tap testing sieve shakers. Material greater than 2 mm diameter was discarded. The sieved fraction was sampled as follows:

(1) Three, 100 gram samples were removed for particle size fractionation by dry sieving through 8-inch diameter screens of the following pore sizes: 1000, 500, 350, 297, 210, 177, 149, 125, 105, 88, and 44 microns in the manner described above for the granular-collector samples. Fractionated material was then quantitatively transferred to 3-ounce seamless boxes, which served both as counting and storage containers.

Activity per unit area values for soil samples were based upon the summation of mean activities of the soil size-fractions. These values were corrected to account for the total weight of soil less than 2 mm in diameter represented by the 1 sq ft soil sample. In cases of extremely low levels of contamination, the fraction background activities were determined by analyzing the size fractions from the 3- to 4-inch deep, subsurface samples and deducting these values from corresponding surface-soil size fractions.

Correction factors for self-absorption were determined for each shot. A series of samples of increasing weights (thickness values ranging from 3 to 860 mg/cm^2) was prepared from a pulverized soil sample contaminated by the particular shot under study. Activity per gram was plotted against sample density to yield a curve which was extrapolated to zero mass. Radioactivity values of samples of different thickness were corrected to account for self-absorption by the ratio of the zero-mass activity to the actual-mass activity.

To account for the changing energy spectrum with time, correction factors were redetermined periodically throughout the radioassay period; and a family of curves was constructed to allow corrections at varying postshot times.

Sr^{90} - Y^{90} standards in 3-ounce seamless cans were used to correct observed count rate data obtained primarily by use of the beta scintillation counters described above. These values were extrapolated to H + 12 hours on the basis of the composite Plumbbob beta decay curve presented in Figure 4.11.

A.3.2 Determination of Beta and Gamma Energy Spectra and Radiation Decay Characteristics

Samples for decay measurements and energy spectra studies consisted of 2-inch diameter discs cut from gummed paper collectors and from gummed paper on which particle size fractions obtained from the GC trays were uniformly spread. These discs were placed in the bottom of plastic culture dishes. Beta radiation was measured by either the anthracene-crystal scintillation probe or 2-inch diameter thin-window methane flow counters.

Gamma-activity levels were determined by use of 2-inch thick, 2-inch diameter, NaI scintillation crystals with equipment identical to that described above for beta-scintillation counting. Efficiencies were determined using Co^{60} standards of similar dimensions and containers to those of the samples.

A recording gamma ray spectrometer (Nuclear Chicago, Model 1820) was used in the determination of gamma energy components and identification of specific gamma emitters. The unit consisted of a radiation analyzer (Model 1810), analytical count rate meter (Model 1621), a scan-control panel, and a 0 to 10 millivolt Brown Instruments Division potentiometer recorder. A 2 inch diameter NaI crystal, mounted in a Nuclear Chicago Model DS-5 scintillation probe and shielded as previously described, served as the radiation detector. Calibration was accomplished using Na^{22}, W^{185}, Sr^{85}, Cs^{137}, and Co^{60} standards.

A.3.3 Determination of Some Physical Characteristics

Individual particles of various particle size fractions greater than 44 microns in diameter were characterized according to color, shape, opacity, and prevalent type. Initial observations were made with a Bausch and Lomb dissecting microscope using magnifications of 10x to 60x. More detailed observations were made using Leitz and Spencer binocular microscopes at magnifications up to 240x. Reflected polychromatic light from a variety of lamps was used. In most cases, observations were made using two to four light sources simultaneously placed at various positions in a 200 degree arc around the specimen stage.

Photomicrographs of notable particles were made using both an Exacta camera with a Visicam microscope adaptor and a Polaroid Land camera. Attempts were made to separate, mechanically, specific particle types within a given size fraction to ascertain any relation between physical appearance and activity.

Selected particle size fractions were separated into magnetic and nonmagnetic components. Each sample was initially transferred to a 20 ml beaker by washing with sufficient isopropyl alcohol to cover the material. The suspension was gently stirred with a magnetic probe consisting of a 5 inch length of glass tubing sealed at one end and fitted with a small Alnico rod magnet which could be withdrawn to free magnetic particles clinging to the tube. The magnetic material so collected was carefully rinsed to free any nonmagnetic component after which the magnet was withdrawn and the magnetic material washed into a container and dried. The nonmagnetic material was recovered by filtering the suspension through a Millipore HA filter. The activity percentage of magnetic fallout was based on the sum of the radioactivities of the magnetic and nonmagnetic components.

A.3.4 Determination of Solubility Characteristics

Radioactive particle size fractions obtained from granular collectors, were tested for solubility in both deionized water and 0.1 $\underline{N}$ HCl. Samples of individual fractions having total beta radioactivities of approximately 10^5 counts/min were shaken by a reciprocating shaker in 17-mm test tubes containing 10 ml of water for 60 minutes. The suspensions were filtered through Millipore filters as described previously. The residues were quantitatively transferred to test tubes containing 10 ml of 0.1 $\underline{N}$ HCl which was shaken and filtered in the same manner. The filtrates, collected in 2-inch diameter glass petri dishes, were evaporated under an infrared lamp prior to beta and gamma radioassay. Residues were transferred to 1 ounce flat seamless tin boxes, also 2 inches in diameter, and were similarly radioassayed. Solubility percentage calculations were based on the sum of soluble and residual radioactivities.

This method provides indices of relative solubility since completeness of solution in either solvent is not implied. However, samples of Diablo and Priscilla fallout of various particle-size classes were exposed to four successive treatments of water and acid to provide indications of rate of solution and completeness of solution resulting from a single treatment by each solvent. Based on the assumption that the radioactivity initially soluble in water is equally soluble in 0.1 N HCl, the acid solubility data reported includes the initial water soluble fraction. Hence, reported acid solubility percentages are considered as if initial acid extractions had been made without prior water treatment.

A.3.5 Radionuclide Analyses

Detailed analyses were made on selected particle size fractions by the Chemical Analysis Group, AEP/ UCLA. Analyses were made for total beta activity and for the following chemically separable radionuclides of the elements barium, cerium, cesium, ruthenium, strontium, yttrium and zirconium. Radiochemical procedures developed by the Health and Safety Laboratory, New York Operations, USAEC, and by the Las Alamos Scientific Laboratory were used on the prepared sample (References 14 and 15).

A.3.6 Analysis of Fallout Debris Persistence Sample

Those samples collected to document the changing concentration of fallout material *per se* (i.e., granular fallout collector, air sampler, and soil) were processed at the Mercury Laboratory. Biological samples, including plants and animals, were processed at the Environmental Radiation Division Laboratory, AEP/UCLA. Film dosimeters were prepared and processed by the Health Physics Section of AEP/UCLA.

A.3.6.1 Fallout Collector and Soil Samples

Serial samples from granular collectors and soil specimens were processed and radioassayed according to procedures described in Section A.3.1.

A.3.6.2 Aerosol Samples

Individual exposed filters from the air-sampler magazines (Section A.2.5) were placed in plastic boxes for radioassay. Samples were assayed at least 96 hours after completion of the sampling interval to allow radon-thoron decay products to reach a relatively low and constant level of activity. The activity values determined for each filter were corrected to midtime of the sample period and average flow rate.

A.3.6.3 Processing and Radioassay of Biological Samples

The procedures used to process and assay both plant and animal samples are presented in detail in Weapons Test WT-1177 (Reference 11) and summarized below.

Animal samples: Frozen small animal samples forwarded to the UCLA Laboratory from the field were thawed and dipped in a mixture of paraffin and beeswax. This step immobilized fallout material on the pelt and minimized contamination from the fur during further processing. Animals were then autopsied to provide weighed samples of skin, GI tract contents, thyroid, lung, liver, kidney, muscle, and bone. The tissues, except thyroid, were reduced in bulk by drying in an oven and then ashed in a muffle furnace at 540° C. Ash residues in aliquots of 500 mg were mounted in 1 inch diameter stainless steel planchets for counting. Fresh thyroid tissue was placed directly into the planchets, macerated, moistened with sodium thiosulphate, gently dried, and counted.

The level of fission product contamination in animal tissue was generally too low to provide satisfactory counting resolution using the available gamma scintillation equipment. Therefore, with the exception of selected samples of thyroid tissue, all animal samples were counted with an end-window GM tube (1.4 mg/cm^2 Anton Model 1001T) for beta activity. Sr^{90} - Y^{90} was used for the standard reference source. Selected thyroid samples were assayed with a gamma spectrometer system fitted with a 2 inch NaI crystal using a Cs^{137} reference source.

Selected samples of each kind of tissue from several conditions of contamination were used to determine beta radioactivity decay and self-absorption factors. These corrections, including ash weight to wet weight conversion factors, were used to adjust the observed counting data to dis/min/gm of fresh tissue and μc/gm of fresh tissue. The reported values are above the average radioactivity determined to be present in tissues prior to the test series, and therefore, the data specifically reflect the accumulation of radionuclides from fallout material due to Operation Plumbbob.

Plant Samples: Bulk plant samples were returned to the UCLA Laboratory where they were dried to a constant weight at 70°C and ground to pass through a 20 mesh screen in a Wiley Mill. Fifty-gram aliquots were counted using the large area flat-plate methane gas flow proportional counters described in Section A.3.1.2.

Fission Product Analysis: Selected samples of animal tissue determined by total beta count to contain enough radioactivity to insure some success in isotopic identification of the contaminants were forwarded to the Chemical Analysis Section for determination of the concentration of the following radionuclides: barium, cerium, cesium, ruthenium, strontium, yttrium and zirconium (Section A.3.5).

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APPENDIX B

EVALUATION OF TWO TYPES OF RADIATION SURVEY INSTRUMENTS

APPENDIX B

EVALUATION OF TWO TYPES OF RADIATION SURVEY INSTRUMENTS

Program 37, CETG, is indebted to the Federal Civil Defense Administration (now the Office of Defense and Civilian Mobilization) for the use of sixty CD V-710 and thirty CD V-700 survey instruments, and to the State of California Civil Defense Organization for the use of thirty-two CD V-700 survey instruments during Operation Plumbbob at the Nevada Test Site.

The two types of instruments are evaluated below with respect to calibration characteristics, field observations, and maintenance[1].

B.1 INSTRUMENT CD V-710-MODEL 4

B.1.1 Calibration

The calibration of these instruments was performed on the Rad-Safe calibration range at NTS utilizing a 0.534 curie Co^{60} radiation source. Attempts were made initially to calibrate using the method recommended by the manufacturer and quoted below

"Prior to recalibrating the instrument, install a new set of batteries. Set the range switch to ZERO position, turn the ZERO control clockwise to the "stop" and adjust the COARSE ZERO control to make the meter read 0.4. Rezero the instrument with the ZERO control.

Check the calibration with the instrument in the case. Remove the instrument and adjust the CALIBRATE control as required. Replace the instrument in the case and check the reading, repeat this procedure until the correct reading is obtained...".

This method proved unsatisfactory because the adjustment of the CALIBRATE control in many cases destroyed the zero adjustment and/or a satisfactory circuit-check reading. The latter situation occurred with an estimated thirty percent of the instruments. A zero adjustment with the range switch at the ZERO position very frequently gave a poor zero value on the X1 scale causing large errors at low radiation levels.

The following procedure was developed by Program 37 personnel primarily to improve the accuracy of readings at low radiation intensity levels (<50 mr/hr)

a. Before entering the radiation field, set COARSE ZERO and CALIBRATE controls to approximate center position. Set zero control on top of instrument to full clockwise position.

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[1] Instrument calibration and maintenance was supervised by J. W. Neel, William Botts, and John Courtier.

b. With the range selector at the X1 position at the 400 mr/hr intensity point on the calibration range, adjust the COARSE ZERO control to bring the meter needle to 400 mr/hr. If this adjustment cannot be accomplished with the COARSE ZERO control, turn the COARSE ZERO control back 1/8 to 1/4 turn and bring needle to read 400 mr/hr with the CALIBRATE control.

c. Out of the radiation field (i.e., <1 mr/hr) of the calibration range, zero the instrument with the ZERO control on top of instrument with the range selector set at the X1 position.

d. Return the instrument to the 400 mr/hr intensity point on the range and readjust the meter needle to read 400 mr/hr with the CALIBRATE control.

e. Recheck zero out of the radiation field and adjust with ZERO control on top of instrument if necessary.

f. Repeat steps (d) and (e) until the instrument reads 400 mr/hr at the 400 mr/hr intensity level and zero at the < 1 mr/hr intensity level (this operation was generally accomplished by three adjustments at each position).

The above procedure was followed by the determination of observed values at true intensity levels of 20, 40, 60, 100, 200, 300, 400, and 500 mr/hr on the X1 scale and at levels of 300, 400, 500, 600, 700, 800, 900 and 1,000 mr/hr on the X10 scale. Calibration at higher radiation intensities was not required by Program 37.

B.1.2. Instrument Characteristics

The following discussion of instrument calibration characteristics is based on 47 instruments which were calibrated by the same four personnel over a 2 day period using the method described above. Prior to calibration, the instruments were determined to have proper battery voltage and to be operating satisfactorily.

Considering the observed dial readings at different levels without regard for the shapes of the respective calibration curves, Tables B.1 and B.2 present data indicative of the magnitude of dial reading deviation from true values and the distribution of such deviations among a number of instruments. Such data indicate the accuracy to be expected at different radiation intensity levels by instruments subjected to the "one-point" calibration procedure described in the foregoing section.

Dial readings on the X1 scale (Table B.1) demonstrate the greatest deviation from true values on the lower one-fifth of the dial, and all instruments generally yielded values within ±25 percent of the true values above the 100 mr/hr radiation level. The maximum accuracy occurred near the center of the dial at the 200 mr/hr level, and accuracy declined at the full scale level where dial readings tended to be low.

The dial readings on the X10 scale, described in Table B.2, all occur on the lower one-fifth of the dial and reflect to a greater degree the high deviation from true values demonstrated on the X1 scale for this portion of the dial. The trend in values

TABLE B.1 Reading Deviation on CD V-710, Model 4, Survey Instruments (X1 Scale)

Deviations on readings at different radiation intensity levels with 47 instruments on the X1 scale.

Dial Reading Deviation Pct of true mr/hr	True mr/hr							
	20	40	60	100	200	300	400	500
	Pct of instruments							
± 0	38	47	43	43	66	36	32	19
≤ ± 5	-	-	-	52	77	66	73	49
≤ ±10	-	-	49	69	92	87	90	72
≤ ±15	-	58	-	75	96	94	96	85
≤ ±20	-	-	64	96	98	100	100	94
≤ ±25	51	67	68	-	100	-	-	96
≤ ±50	64	90	96	100	-	-	-	-
≤ ±75	-	94	100	-	-	-	-	-
≤ ±100	90	100	-	-	-	-	-	-
≤ ±150	94	-	-	-	-	-	-	-
≤ ±200	100	-	-	-	-	-	-	-
No. of Meters off scale	-	-	-	-	-	-	4	-

TABLE B.2 *Reading Deviation on CD V-710, Model 4, Survey Instruments (X10 Scale)*

Deviations on readings at various radiation intensity levels with 47 instruments on the X10 scale.

Dial Reading Deviation, Pct of true mr/hr	True mr/hr							
	300	400	500	600	700	800	900	1,000
	Pct of instruments							
± 0	19	24	19	23	21	30	28	28
≤ ±5	-	30	21	29	-	-	-	45
≤ ±10	21	-	32	38	34	41	39	62
≤ ±15	-	34	36	-	-	56	64	77
≤ ±20	23	36	62	57	72	71	79	98
≤ ±25	27	53	-	66	-	94	96	-
≤ ±50	66	81	92	100	100	100	100	100
≤ ±75	81	98	100	-	-	-	-	-
≤ ±100	98	-	-	-	-	-	-	-
No. of Meters with no response	2	2	-	-	-	-	-	-

for dial readings suggests that deviations would decrease at higher radiation levels. All instruments yielded values within ± 50 percent and the majority within ± 20 percent of true values from 600 to 1000 mr/hr.

Considering the accuracy of dial readings of individual instruments over the range of radiation intensities investigated and excluding the lowest of 20 mr/hr level, 34 percent of the instruments demonstrated deviations with ± 10 percent of the true value on the X1 scale and 19 percent of the instruments demonstrated deviations on the X10 scale (to a maximum true level of 1000 mr/hr). Six percent of the instruments demonstrated deviation within ± 10 percent of the true values on both the X1 and X10 scale.

Indications of "Zero Creep" are obtained by analysis of dial readings over the 20 to 100 mr/hr range on the X1 scale of instruments with aberrant X10 scale readings. Thirteen of 14 instruments which read high throughout the X10 scale range or at the lower levels also demonstrated high dial readings at intensity levels of 20 to 100 mr/hr on the X1 scale (where "Zero Creep" would be most detectable). Conversely, only one of 20 instruments which yielded low dial readings on the X10 scale also demonstrated low readings over the 20 to 100 mr/hr range on the X1 scale.

B. 1. 3 Field Observations

Other than instrument malfunction caused by electronic difficulties, the primary complaint of Program 37 field personnel concerned the zero adjustment. The adjustment knob itself is not sufficiently protected to prevent accidental jarring. Erroneous readings, usually high, were obtained after the jarring of the adjustment knot. These were particularly noticeable at low radiation intensity values (20 to 40 mr/hr) when the instruments were used in conjunction with 0 to 50 mr/hr GM type instruments.

Radiation measurements obtained by U. S. Army AN/PDR-TIB and CD V-710 survey instruments at the same locations in fallout contaminated areas indicated that the two instruments yielded equivalent values upon the application of calibration correction factors to observed readings.

B. 1. 4 Maintenance

The calibration and coarse zero potentiometers were of poor quality, and instrument malfunction in the field was often attributable to loose contacts on these two potentiometers. Some electrometer tubes required replacement but the number was not unreasonable in terms of the number of instruments involved.

B. 2 INSTRUMENT CD V-700

B. 2. 1 Calibration

The calibration of CD V-700 instruments was performed on a special course established at Mercury utilizing a 10 mg radium source. The internal source was not useful in adjusting instrument sensitivity prior to range calibration; the few instruments which demonstrated highly aberrant values were adjusted at medium radiation intensities on the calibration range. Observed values were obtained at true intensity levels of 0.01, 0.03, 0.05, 0.07, 0.1, 0.3, 0.4, and 0.5 mr/hr on the X1 scale; at 0.5, 1, 3, 4, and 5 mr/hr on the X10 scale; and at 1, 5, 10, 20, 30, 40, and 50 mr/hr on the X100 scale.

B.2.2 Instrument Characteristics

Unless otherwise indicated, the following discussion of instrument calibration characteristics is based on 43 instruments which were calibrated over a 17 day period by the same four personnel. Prior to calibration, the instruments were checked with respect to proper battery voltage and satisfactory operation.

Tables B.3, B.4, and B.5 indicate the magnitude of dial reading deviation from true values and the distribution of such deviations among a number of instruments. Dial reading deviations on the X1 scale are described in Table B.3; over the range of 0.1 to 0.5 mr/hr, 50 percent or more of the instruments indicated values within ± 10 percent of true values. The maximum efficiency occurred at 0.4 mr/hr. A relatively large number of instruments (35 percent) were off scale at the 0.5 mr/hr intensity level.

At true intensity levels of less than 0.1 mr/hr, dial readings were more erratic as is to be expected when background levels are approached. Background activity levels were determined on 18 instruments: 5 instruments (28 percent) demonstrated a background level of 0.01 mr/hr; 8 instruments (44 percent), a level of 0.02 mr/hr; 4 instruments (22 percent), a level of 0.03 mr/hr; and 1 instrument (5 percent), a level of 0.06 mr/hr. By inspection, background values did not generally affect dial readings above 0.1 mr/hr and in many cases, above 0.05 mr/hr.

Dial reading deviations on the X10 scale are described in Table B.4. Seventy-four percent of the instruments demonstrated readings within ± 50 percent of true values over the range from 0.5 to 5 mr/hr. Twenty-six percent of the instruments were off scale at the 5 mr/hr level. Over 50 percent of the instruments yielded values within ±10 percent of true values from 0.5 to 5 mr/hr.

Dial reading deviations on the X100 scale are described in Table B.5. The greatest accuracy occurred near the center of the dial where 72 percent of the instruments yielded correct values at the 20 mr/hr intensity level. While 1 mr/hr values were quite erratic, 70 percent of the instruments demonstrated values which were accurate to ±50 percent of true values over the range from 5 to 50 mr/hr; 30 percent of the instruments were off scale at the 50 mr/hr level. However, over the same range, more than 50 percent of the instruments demonstrated values which were accurate to ±10 percent of true values.

TABLE B.3 Reading Deviation on CD V-700 Survey Instruments (X1 Scale)

Deviations on readings at various radiation intensity levels with 43 instruments on the X1 scale.

Dial Reading Deviation, Pct of true mr/hr	True mr/hr							
	0.01	0.03[a]	0.05	0.07[a]	0.1	0.3	0.4	0.5
	Pct of instruments							
± 0	14	49	47	39	40	49	60	37
≤ ± 5	-	-	-	-	-	60	67	51
≤ ± 10	-	-	-	-	49	63	70	-
≤ ± 15	-	-	-	78	-	88	86	53
≤ ± 20	-	-	77	-	67	-	93	63
≤ ± 25	-	-	-	-	-	93	95	65
≤ ± 50	-	88	91	95	91	100	100	-
≤ ± 75	-	93	95	-	93	-	-	-
≤ ± 100	60	95	100	100	100	-	-	-
≤ ± 150	-	-	-	-	-	-	-	-
≤ ± 200	91	100	-	-	-	-	-	-
≤ ± 300	-	-	-	-	-	-	-	-
≤ ± 400	95	-	-	-	-	-	-	-
≤ ± 600	100	-	-	-	-	-	-	-
No. of Meters off-scale	-	-	-	-	-	-	-	35

[a] 41 instruments were used at this level

TABLE B.4 Reading Deviation on CD V-700 Survey Instruments (X10 Scale)

Deviations on readings at various radiation intensity levels with 43 instruments on the X10 scale.

Dial Reading Deviation, Pct of true mr/hr	True mr/hr				
	0.5[a]	1[b]	3	4	5
	Pct of Instruments				
± 0	63	35	28	35	40
≤ ± 5	-	-	37	58	44
< ± 10	69	85	70	74	60
≤ ± 15	-	88	72	93	63
< ± 20	88	92	95	98	72
< ± 25	-	-	100	100	-
≤ ± 50	100	100	-	-	74
No. of Meters off scale	-	-	-	-	26

[a] 16 instruments used at this level

[b] 26 instruments used at this level

TABLE B.5 Reading Deviation on CD V-700 Survey Instruments (X100 Scale)

Deviations on readings at various radiation intensity levels with 43 instruments on the X100 scale.

Dial Reading Deviation, Pct of true mr/hr	True mr/hr 1	5	10	20	30	40	50
	Pct of instruments						
≤± 0	47	51	56	72	33	12	12
≤± 5	-	-	60	88	77	65	26
≤± 10	-	72	88	93	95	86	51
≤± 15	-	-	-	98	98	95	60
≤± 20	-	93	95	-	-	-	67
≤± 25	-	95	-	100	-	100	70
≤± 50	74	100	100	-	100	-	-
≤± 75	77	-	-	-	-	-	-
≤± 100	91	-	-	-	-	-	-
≤± 150	98	-	-	-	-	-	-
≤± 200	100	-	-	-	-	-	-
No. of Meters off-scale	-	-	-	-	-	-	30

Considering the accuracy of dial readings of individual instruments over the ranges of 0.1 to 0.5 mr/hr on the X1 scale, 1 to 5 mr/hr (or 3 to 5 mr/hr for 17 instruments) on the X10 scale, and 5 to 50 mr/hr on the X100 scale, the percent of instruments yielding values within ± 10 percent of true values were 19, 47, and 44 percent on the X1, X10, and X100 scales, respectively. Nine percent of the instruments demonstrated dial readings within ± 10 percent of true values on all three scales. Approximately 12 percent of the instruments were off scale at the maximum value on all three scales.

B.2.3. Field Observations

The CD V-700 survey instrument was a reliable field instrument, and the 50 mr/hr range proved very advantageous when used in conjunction with the CD V-710 ion chamber instruments with their attendant inaccuracies in the 20 to 40 mr/hr range.

The major complaint of Program 37 field personnel concerned dial needle fluctuation where measurements of radiation levels of less than 2 mr/hr were attempted.

Comparisons of the CD V-700 survey instrument to other types of instruments with respect to measurement of intensity levels of fallout radiation were minimal. However, one comparison of fallout radiation measurement by the CD V-700 and the U. S. Army AN/PDR-T1-B instruments was obtained during Operation Plumbbob. Radiation measurements were obtained at various times after H hour at a single location and the observed radiation intensity values corrected by appropriate calibration factors. The data appear in Table B.6.

Over the time period from H + 9.4 to H + 12.4 hours, the measurements by the CD V-700 instrument ranged from 88.8 to 72.7 percent of those obtained by the T1-B ion chamber instrument. The fact that the ratio varied with time after a shot may well reflect differential energy responses of the two instruments; however, results based on single instruments of each type cannot be considered conclusive in view of the variability demonstrated in the foregoing sections by instruments of the same type.

TABLE B.6 Comparison of Fallout Radiation Measurements Made by CD V-700 and U.S. Army AN/PDR-T1-B Survey Instruments.

Time after shot, H+hours	Fallout radiation intensity, mr/hr T1-B	Fallout radiation intensity, mr/hr V-700		Ratio V-700/T1-B x 100
9.43	18.8	16.7		88.8
10.45	18.2	14.6		80.2
10.93	17.9	13.6		76.0
11.50	16.5	13.0		78.8
11.93	15.8	12.4		78.5
12.43	15.0	10.9		72.7
			Mean	79.2

B.2.4 Maintenance

The primary source of instrument malfunction was related to the CK 6418 tubes which require frequent replacement in terms of the number of hours of operation.

B.3 DISCUSSION AND SUMMARY

The results of dial reading versus true radiation intensity determinations (in mr/hr) derived from the calibration of more than 40 instruments each of the CD V-700 and CD V-710 types are summarized in Table B.7 with respect to the percent of instruments demonstrating dial readings within ± 10 percent of true values.

The CD V-700 values generally indicate greater accuracy than those of the CD V-710 ion chamber over the lower portion of the meter dial; however, a relatively large number of instruments were off scale at the maximum points on each of the three scales of the CD V-700 instrument.

TABLE B.7 Percent of Survey Instruments Demonstrating Dial Readings Within ± 10 Percent of True Values at Various Radiation Intensity Levels.

	Pct of instruments within ± 10 pct of true mr/hr value				
	CD V-700			CD V-710	
	Scale			Scale	
True mr/hr value	X 1	X 10	X 100	X 1	X 10
0.01	14	-	-	-	-
0.03	49	-	-	-	-
0.05	47	-	-	-	-
0.07	39	-	-	-	-
0.1	49	-	-	-	-
0.3	63	-	-	-	-
0.4	70	-	-	-	-
0.5	51	69	-	-	-
1	-	85	47	-	-
3	-	70	-	-	-
4	-	74	-	-	-
5	-	60	72	-	-
10	-	-	88	-	-
20	-	-	93	38	-
30	-	-	95	-	-
40	-	-	86	47	-
50	-	-	51	-	-
60	-	-	-	49	-
100	-	-	-	69	
200	-	-	-	92	-
300	-	-	-	87	21
400	-	-	-	90	30
500	-	-	-	72	32
600	-	-	-	-	38
700	-	-	-	-	34
800	-	-	-	-	41
900	-	-	-	-	39
1000	-	-	-	-	62
No. of Meters off scale at maximum	35	26	30	4	-

The percentages of each type of instrument which demonstrated dial readings within ± 10 percent of true values over essentially full dial deflection on different scales (except for the CD V-700, X10 scale) are summarized in Table B.8. These data show that the CD V-710 instrument is relatively acceptable on the lowest scale.

It is obvious, however, that the calibration at low radiation intensities (<1000 mr/hr) discriminates against the CD V-710 instrument since the majority of the readings obtained were on the lower one fifth of the dial as well as being much below the probable optimal radiation intensity range for which the instrument is designed.

Field and maintenance observations are summarized in Table B.9.

TABLE B.8 Percent of Instruments Demonstrating Dial Readings Within ± 10 Percent of True Values Over Various Intensity Ranges.

True mr/hr Range	Pct of instruments within ± 10 pct of true mr/hr value		
	Scale		
	X 1	X 10	X 100
CD V-700			
0.1-0.5	19	-	-
1-5	-	47	-
5-50	-	-	44
0.1-50	-	9	-
CD V-710			
40-500	34	-	-
300-1000	-	19	-
40-1000	-	6	-

TABLE B.9 Field and Maintenance Observations of Survey Instruments

Instrument	Field Observations	Maintenance Observations
CD V-700	Difficult measurement of levels less than 2 mr/hr due to needle fluctuation. A generally reliable field instrument with a very useful range (50 mr/hr).	Frequent replacement of CK 6418 tubes; other maintenance minimal.
CD V-710	Inadequate ZERO CONTROL protection; inaccurate at low radiation levels (less than 50 mr/hr). Instrument was not used by Program 37 at optimal radiation intensities.	Frequent loose contacts on CALIBRATE and COARSE ZERO potentiometers which are of poor quality for durable field instruments.

APPENDIX C

ACTIVITY PER SQUARE FOOT, FALLOUT TIME OF ARRIVAL, AND PERCENTAGE OF THE MATERIAL WITHIN FALLOUT PATTERNS FROM SHOTS BOLTZMANN, PRISCILLA, AND SMOKY

TABLE C.1 Activity Per Square Foot, Fallout Time of Arrival, and Percentage of the Less Than 44 Micron Material Within Fallout Patterns from Shots Boltzmann, Priscilla, and Smoky

Total β activity values corrected to H + 12 hours, average of duplicate sample areas each 4.73 sq ft. Exceptions indicated by superscript a, from single sample area. deg-min, degrees-minute. NM, not measured. S, one sq ft surface soil sample 1 inch deep. For locations of arcs within the patterns see Figures 2.1, 2.3 and 2.7a.

Sta. No.	Station Location		Miles from Midline	Miles from GZ	Bearing from GZ, deg-min	Fallout time, H + hour	Total β activity, μc/sq ft	Pct <44 micron fraction deposited
	Miles	Reference						
Shot Boltzmann, Arc I								
0120	9.4	W of Standard on road 1 miles S and parallel to Standard road	6.2 W	38.0	323-45	2.9	2.23	66
0119	8.4		5.8 W	36.8	324-05	2.8	2.67	63
0118	7.4		5.2 W	35.9	324-25	2.6	56.9	23
0117	7.0	SW of Standard on road to dry lake	4.9 W	35.4	324-40	2.5	2.16	60
0116	6.7		4.6 W	35.6	325-15	2.2	28.5	30
0115	5.7		3.7 W	35.9	326-45	1.8	120	42
0114	4.7	W of Standard on Standard road	3.0 W	36.3	328-05	1.7	655	24
0113	3.7		2.0 W	36.3	324-35	1.6	895	22
0112	2.7		1.0 W	36.2	331-20	1.5	981	22
0111	1.6	(Midline)	-0-	36.3	332-55	1.4	1230	20
0110	0.6		0.6 E	35.9	334-05	1.4	1290	19
0109	0.4	E of Standard on Standard road	1.5 E	35.2	335-00	1.5	796	22
0108	1.6		2.3 E	35.0	336-30	1.5	852	13
0107	2.6		3.2 E	34.5	338-10	1.7	921	54
0106	3.6		4.1 E	34.5	339-30	1.8	204	39
0105	4.6		5.1 E	34.3	341-15	2.0	31.7	12
0104	5.6		6.2 E	34.0	342-50	2.5	4.88	26
0103	6.6		7.2 E	34.0	344-35	3.0	4.18	69
0102	7.6		8.2 E	34.0	346-25	3.8	0.91	73
0101	8.6		9.2 E	34.0	348-00	4.2	0.53	92
Shot Boltzmann, Arc II								
0201	40	W of Reed on old Nev. 25	20.0 W	68.9	323-15	3.9	3.62[a]	76
0202	39		19.8 W	67.9	323-00	3.9	3.71[a]	83
0203	38		19.4 W	66.8	323-05	3.8	8.55	87
0204	37		19.0 W	65.8	323-00	3.8	3.97[a]	77
0205	36		18.9 W	64.8	323-05	3.8	NM	--
0206	35		18.6 W	63.9	323-10	3.8	NM	--
0207	34		18.0 W	62.9	323-15	3.7	NM	--
0208	33		17.4 W	61.8	323-20	3.7	5.71	88
0209	32		16.8 W	60.9	323-50	3.6	2.75[a]	88
0210	31		15.8 W	60.1	324-15	3.6	NM	--
0211	30		15.0 W	59.1	324-40	3.5	NM	--
0212	29		14.0 W	58.3	324-05	3.4	NM	--
0213	28		13.0 W	57.5	325-35	3.3	3.60[a]	90
0214	27		12.2 W	56.6	326-05	3.2	NM	--
0215	26		11.3 W	55.7	326-40	3.1	NM	--
0216	25		10.8 W	54.8	327-00	3.0	NM	--
0217	24		10.0 W	53.8	327-25	3.0	NM	--
0218	23		9.2 W	53.0	327-50	2.9	1.48[a]	82
0219	22		8.5 W	52.2	328-35	2.8	3.76[a]	75
0220	21		7.4 W	51.6	329-25	2.7	19.0	40
0301	20.0		6.1 W	51.0	330-20	2.6	117	27
0321	19.5		5.8 W	50.8	330-50	2.5	151 (S)	--
0302	19.0		5.1 W	50.4	331-20	2.4	275	29
0303	18.0		4.2 W	50.0	332-15	2.3	284	30
0304	17.0		3.3 W	49.6	333-10	2.2	246	31
0305	16.0		2.3 W	49.1	334-05	2.2	253	43
0322	15.2		1.8 W	48.8	334-55	2.2	422 (S)	--
0306	15.0		1.5 W	48.7	335-20	2.1	686	30
0307	14.0		0.5 W	48.3	336-15	2.1	632	32
0323	13.5	(Midline)	-0-	48.1	336-55	2.0	1119 (S)	--
0308	13.0		0.7 E	47.9	337-25	2.0	1120	23
0309	12.0		1.5 E	47.4	338-25	2.0	450	17
0310	11.0		2.3 E	47.8	339-45	2.0	297	40

TABLE C.1 (contd)

Sta. No.	Station Location: Miles	Station Location: Reference	Miles from Midline	Miles from GZ	Bearing from GZ, deg-min	Fallout time, H + hour	Total β activity, μc/sq ft	Pct <44 micron fraction deposited
Shot Boltzmann, Arc II (contd)								
0311	10.0	W of Reed on old Nev. 25	3.6 E	47.2	340-50	2.0	215	25
0312	9.0		4.3 E	47.1	341-55	2.0	119	42
0313	8.0		5.2 E	47.0	343-05	2.2	54.3	10
0314	7.0		6.1 E	47.0	344-15	2.6	28.6	38
0315	6.0		7.2 E	46.9	345-30	3.0	2.17	78
0316	5.0		8.2 E	45.8	346-30	3.5	3.99	63
0317	4.0		9.2 E	46.5	347-50	4.0	7.14	72
0318	3.0		10.1 E	46.4	349-00	4.5	4.60	58
0319	2.0		12.0 E	46.5	350-10	5.0	4.78	85
0320	1.0		13.0 E	46.5	351-20	5.5	1.92	68
Shot Boltzmann, Arc III								
0520	39.0	W of Warm Springs on U. S. No. 6	29.1 W	87.9	321-20	5.2	3.07	87
0519	37.0		28.5 W	86.8	322-25	5.0	3.02	85
0518	35.1		25.6 W	85.8	323-30	4.8	3.70	80
0517	33.1		24.0 W	85.4	324-35	4.7	3.45	86
0516	31.3		22.5 W	85.6	325-35	4.7	3.49	86
0515	29.3		20.9 W	85.4	326-45	4.5	3.03	96
0514	27.1		19.1 W	84.5	328-05	4.4	10.1	76
0513	25.1		17.5 W	83.3	329-05	4.2	8.92	58
0512	23.0		16.5 W	82.2	330-20	4.0	11.1	50
0511	21.0		14.0 W	82.2	331-30	3.9	25.7	49
0510	19.0		12.3 W	81.2	332-40	3.8	63.0	52
0509	17.1		10.6 W	80.8	334-00	3.7	73.4	43
0508	15.0		8.5 W	80.2	335-30	3.7	56.6	50
0507	13.0		6.5 W	79.8	337-00	3.7	49.5	80
0506	11.0		4.8 W	79.2	338-15	3.7	37.0	53
0505	9.0		3.6 W	79.0	339-45	3.7	66.5	59
0523	7.6		1.1 W	78.7	340-45	3.7	239 (S)	--
0504	7.0		0.8 W	78.7	341-10	3.7	1310	74
0522	6.6		0.2 W	78.6	341-30	3.7	942 (S)	--
--	6.4	(Midline)	-0-	78.5	341-45	3.7	NM	--
0521	6.0		0.2 E	78.4	341-55	3.7	934	--
0503	5.0		1.0 E	78.1	342-35	3.7	572	76
0502	3.1		3.0 E	78.0	344-00	3.8	284	65
0501	1.0		5.3 E	77.9	345-30	4.0	10.9	75
Shot Priscilla, Arc I								
0107	38.1	N of Indian Springs AFB on Indian Springs road	15.0 N	26.7	028-55	2.9	0.72	81
0106	37.0		14.0 N	25.1	031-50	2.8	1.13	82
0105	36.0		12.9 N	24.7	033-00	2.8	1.72	82
0104	35.0		11.9 N	24.1	035-15	2.8	1.95	85
0103	34.0		11.1 N	23.8	037-05	2.7	2.96	82
0102	33.0		10.0 N	23.8	039-50	2.7	4.26	85
0101	32.0		9.1 N	23.6	042-10	2.6	5.12	81
0108	30.8		8.1 N	23.5	044-30	2.6	10.3	83
0109	29.8		7.0 N	23.2	046-30	2.5	9.05	81
0110	28.8		6.1 N	22.0	048-35	2.5	8.99	82
0111	27.8		5.1 N	21.0	050-15	2.4	7.49	77
0112	26.8		4.3 N	20.3	052-00	2.4	9.68	74
0113	25.8		3.6	19.6	053-55	2.3	8.53	83
0114	24.8		2.9 N	19.0	056-25	2.2	43.7	67
0115	23.8		1.9 N	18.4	059-10	2.4	126	65
0124	23.3		1.1 N	18.1	060-40	2.4	467 (S)	--
0116	22.8		0.8	18.0	062-00	2.5	82.4	53
--	21.9	(Midline)	-0-	17.8	064-30	2.5	--	--
0117	21.8		0.1 S	17.8	064-50	2.5	115	57
0118	20.8		1.0 S	17.4	067-55	2.6	77.1	70

TABLE C.1 (contd)

Sta. No.	Station Location: Miles	Station Location: Reference	Miles from Midline	Miles from GZ	Bearing from GZ, deg-min	Fallout time, H + hour	Total β activity, μc/sq ft	Pct <44 micron fraction deposited
Shot Priscilla, Arc I (contd)								
0119	19.8	N of Indian Springs AFB on Indian Springs road	2.0 S	17.0	071-15	2.7	22.2	65
0127	19.3		2.4 S	16.9	073-15	2.8	105 (S)	--
0120	19.0		2.9 S	16.8	074-25	2.8	2.11	70
Shot Priscilla, Arc II								
0301	20.6	N of Kane Springs road on U. S. No. 93	14.0 N	55.5	053-20	4.7	2.57[a]	77
0302	19.6		13.0 N	55.5	055-10	4.5	2.85[a]	73
0205	18.7		12.1 N	55.8	056-05	4.4	1.06[a]	86
0206	17.8		11.6 N	55.8	057-05	4.4	1.43[a]	92
0304	17.6		11.4 N	55.9	057-25	4.3	1.84[a]	89
0305	16.4		10.3 N	56.4	058-10	4.3	1.37[a]	91
0306	15.5		9.3 N	57.5	059-15	4.2	1.33[a]	87
0207	14.7		8.4 N	57.0	060-05	4.1	1.17[a]	85
0208	13.9		7.6 N	56.7	060-45	4.0	0.880[a]	82
0209	13.0		6.9 N	56.2	061-40	3.9	1.28[a]	79
0210	12.2		6.2 N	56.0	062-25	3.9	2.50[a]	71
0211	11.3		5.3 N	55.8	063-05	3.8	3.61[a]	72
0212	10.4		4.6 N	55.9	064-05	3.8	9.32	78
0213	9.5		3.6 N	55.8	065-15	3.8	18.8	77
0214	8.6		2.8 N	55.7	066-05	3.7	27.4	66
0215	7.7		1.8 N	55.7	067-10	3.8	45.6	71
0216	6.8		1.0 N	55.5	068-15	3.8	67.9	69
0224	6.4		0.6 N	55.2	069-10	3.9	170 (S)	--
0217	5.8		0.1 N	54.9	068-50	3.9	75.5	64
--	5.7	(Midline)	-0-	54.9	068-55	3.9	NM	--
0223	5.3		0.4 S	54.9	069-15	3.9	154 (S)	--
0218	5.0		0.8 S	54.9	069-45	4.0	54.7	73
0219	4.2		1.6 S	54.8	070-20	4.0	30.4	71
0220	3.3		2.5 S	55.0	071-20	4.1	14.4	85
0307	1.4		3.5 S	55.3	072-35	4.3	2.25[a]	84
0308	0.4		4.5 S	55.7	074-00	4.4	1.17[a]	82
Shot Priscilla, Arc III								
0801	36.1	NE of U. S. No. 93 on Kane Springs road	10.9 N	86.0	062-20	6.8	3.76	80
0802	35.3		10.0 N	84.4	062-45	6.7	4.47	81
0803	34.4		9.3 N	83.9	062-55	6.7	4.78[a]	77
0804	33.5		8.9 N	83.0	063-10	6.6	5.65	84
0805	32.7		8.4 N	82.2	063-20	6.5	5.47	77
0806	31.8		7.9	81.5	063-35	6.4	5.24	77
0807	30.9		7.3 N	80.8	063-53	6.2	5.66	80
0808	30.0		6.9 N	80.1	064-15	6.1	6.34	83
0809	29.0		6.2 N	79.3	064-35	6.0	4.73	73
0810	28.0		5.7	78.7	064-50	5.9	9.77	80
0811	27.1		5.3 N	78.0	065-05	5.7	10.1	80
0812	26.3		5.0 N	77.2	065-15	5.5	13.2	84
0813	25.3		4.5 N	76.3	065-30	5.4	11.0	82
0814	24.5		4.0 N	75.5	065-50	5.3	12.8	78
0706	19.8		1.8 N	72.1	067-05	5.2	24.0[a]	68
0707	19.1		1.1 N	71.4	067-20	5.1	17.5	72
0708	18.3		0.8 N	70.5	067-45	5.1	18.6	79
0816	18.2		0.8 N	70.4	067-45	5.0	76.1	--
0817	17.8		0.7 N	70.2	067-50	5.0	103 (S)	--
0709	17.5		0.6 N	70.0	067-55	5.0	29.0	70
0710	16.8		0.4 N	69.3	068-10	5.0	24.5	69
0711	16.0		0.2 N	68.8	068-25	4.4	31.2	89
0723	15.5	(Midline)	-0-	68.4	068-35	4.4	163 (S)	--
0712	15.2		0.2 S	68.1	068-45	4.4	32.2	73
0725	14.8		0.5 S	67.9	068-20	4.4	102 (S)	--

TABLE C.1 (contd)

Sta. No.	Station Location Miles	Station Location Reference	Miles from Midline	Miles from GZ	Bearing from GZ deg-min	Fallout time, H + hour	Total β activity, μc/sq ft	Pct <44 micron fraction deposited
Shot Priscilla, Arc III (contd)								
0713	14.5	NE of U. S. No. 93 on Kane Springs road	0.7 S	67.4	068-00	4.4	25.0	74
0819	14.2		0.8 S	67.2	068-05	4.4	55.9 (S)	--
0714	13.7		0.9 S	67.0	069-15	4.4	17.2	78
0715	12.9		1.1 S	66.3	069-35	4.4	8.85	80
0716	12.2		1.6 S	65.5	069-55	4.4	6.78	76
0727	11.7		1.7 S	65.2	070-00	4.4	23.9 (S)	--
0717	11.4		1.8 S	65.0	070-05	4.4	5.10	81
0820	11.1		1.8 S	64.8	070-10	4.4	80.8 (S)	--
Shot Priscilla, Arc IV								
0920	2.3	W of Utah 16 on Utah 56	22.8 N	143	062-00	13.0	1.36[a]	82
0919	0.5		21.8 N	144	063-35	12.6	1.07[a]	88
0918	10.6	E of Utah 18 on Utah 16	21.0 N	144	063-55	12.3	1.25[a]	79
0917	9.0		20.0 N	142	063-05	12.1	1.33[a]	81
0916	7.2		18.9 N	141	064-15	11.5	1.99[a]	82
0915	5.6		17.9 N	139	064-45	11.0	1.84[a]	82
0914	3.5		17.0 N	137	064-50	10.7	2.11[a]	81
0913	1.9		16.1 N	135	065-00	10.4	2.04[a]	78
0912	19.6	N of Veyo on Utah 18	15.7 N	133	065-55	10.0	2.57[a]	NM
0911	17.7		14.3 N	134	065-35	9.9	4.25[a]	66
0910	16.0		13.4 N	135	066-05	8.5	2.76[a]	80
0909	14.4		12.3 N	136	066-40	7.7	3.45[a]	72
0908	12.5		10.3 N	135	067-25	7.1	5.08	73
0907	10.8		8.6 N	135	068-15	7.1	5.18	78
0906	8.9		6.9 N	135	069-00	7.1	5.02	77
0905	7.2		5.3 N	134	069-30	7.1	5.08	84
0904	5.5		3.5 N	133	070-15	7.1	6.68	85
0903	3.7		3.1 N	132	070-40	7.1	7.82	81
0902	1.8		1.0 N	130	071-10	7.1	9.17	85
0901	0.1		0.1 N	129	071-30	7.1	13.4	80
		(Midline)	-0-	129	071-10	--	--	--
1001	0.4	S. of Veyo on Utah 18	0.3 S	128	071-35	7.1	10.5	75
1002	3.9		1.0 S	126	071-55	7.0	10.7	72
1003	6.6		2.9 S	124	072-05	7.0	6.55	69
1004	9.3		5.0 S	123	073-30	7.2	5.79	83
1005	11.8		6.8 S	122	074-35	7.4	5.24	76
1006	14.8		9.2 S	122	075-50	7.6	3.31[a]	73
Shot Priscilla, Arc V								
0420	8.6	N of Utah 56 (Cedar City) on U. S. No. 91	28.0 N	176	065-35	14.0	0.79[a]	88
0419	5.5		26.3 N	173	065-45	13.9	1.99[a]	89
0418	2.4		24.0 N	171	066-20	13.5	1.30[a]	77
0417	1.2	S of Utah 56 (Cedar City) on U. S. 91	19.5 N	169	067-40	13.0	1.55[a]	87
0416	4.3		17.2 N	166	068-05	12.6	1.80[a]	88
0415	7.3		15.8 N	168	068-15	12.4	2.41[a]	81
0414	10.4		12.9 N	162	069-10	11.9	3.95[a]	82
0413	13.5		10.0 N	159	070-00	11.5	3.60[a]	85
0412	16.5		7.5 N	157	070-45	11.1	4.48[a]	85
0411	19.6		4.5 N	155	071-45	9.8	5.79	82
0410	22.7		1.6 N	154	072-40	9.2	8.23	83
0421	25.1	(Midline)	-0-	153	073-10	8.9	25.4 (S)	--
0409	25.7		1.0 S	152	073-35	8.6	8.0	86
0422	28.6		3.5 S	157	074-15	8.5	170 (S)	--
0408	28.8		3.7 S	150	074-35	8.5	6.88	86
0407	31.7		6.1 S	148	076-25	9.2	6.79	83
0406	34.9		8.5 S	146	076-10	10.0	6.45	87
0405	37.9		10.5 S	144	077-45	10.1	4.52[a]	73

TABLE C.1 (contd)

Sta. No.	Station Location: Miles	Station Location: Reference	Miles from Midline	Miles from GZ	Bearing from GZ, deg-min	Fallout time, H + hour	Total β activity, μc/sq ft	Pct <44 micron fraction deposited
Shot Priscilla, Arc V (contd)								
0404	41.0	S of Utah 56 (Cedar City) on U. S. 91	12.8 S	142	077-35	10.1	4.18[a]	78
0403	44.0		15.2 S	139	078-25	10.1	1.67[a]	80
0402	47.1		16.2 S	136	078-50	10.0	1.17[a]	78
0401	50.2		16.3 S	134	078-55	9.7	0.355[a]	94
Shot Priscilla, Arc VI								
0501		Hatch, Utah	20.0 N	200	071-10	11.8	1.17[a]	90
0521	2.6	S of Hatch on U. S. 89	18.0 N	199	071-35	11.5	19.3 (S)	--
0503	5.3		15.7 N	198	072-15	11.1		
0504	7.9		13.1 N	196	072-50	10.8	1.40[a]	76
0505	10.5		10.8 N	196	073-30	10.5	2.12[a]	81
0506	13.2		8.4 N	194	074-05	10.2	3.06[a]	75
0507	15.8		6.1 N	192	074-45	9.8	3.78[a]	77
0508	18.4		3.8 N	191	075-20	9.5	6.33	78
0523	19.3		2.8 N	190	075-35	9.4	31.0 (S)	--
0509	21.1		1.6 N	189	075-50	9.4	6.59	71
0510	23.7	(Midline)	-0-	188	076-15	9.5	8.85	78
0511	26.3		2.5 S	187	076-55	9.7	3.28	83
0512	28.9		4.5 S	186	077-30	9.8	3.05	90
0513	31.6		6.7 S	184	078-00	10.0	2.04[a]	79
0527	34.2		8.5 S	182	078-30	10.1	12.9 (S)	--
0515	36.8		10.5 S	181	079-05	10.3	NM	--
0516	39.5		12.3 S	182	079-40	10.6	NM	--
0517	42.1		13.2 S	184	080-10	10.7	0.93[a]	78
Shot Smoky, Arc I								
0101	2.0	S of Gate 385 on Mercury Hwy		1.2	102-40	NM	Collector Destroyed by Blast	
0102	3.0			2.0	131-05	NM	Collector Destroyed by Blast	
0103	4.0		1.0 S	2.8	140-15	-0-	Collector Destroyed by Blast	
0104	5.0		1.4 S	3.7	150-05	0.1	Collector Destroyed by Blast	
0105	6.0		2.8 S	4.6	164-30	0.2	953	2.9
0106	7.0		3.7 S	5.3	168-35	0.3	1020	5.0
0107	8.0		4.7 S	6.3	169-20	0.4	894	5.5
0108	9.0		5.5 S	7.3	170-50	0.5	362	24
0109	10.0		6.3 S	8.3	173-05	0.7	325	8.5
0110	11.0		7.1 S	9.2	174-30	1.0	141	12
0111	12.0		8.1 S	10.4	174-55	1.2	NM	--
0112	13.0		8.8 S	11.3	175-30	1.5	16.5	26
0113	14.0		9.8 S	12.3	175-40	1.7	13.4[a]	38
0114	15.0		10.6 S	13.3	175-50	1.8	24.7	40
0115	16.0		11.6 S	14.3	175-55	2.1	12.9	61
0116	17.0		12.5 S	15.4	176-05	2.4	14.7	43
0117	18.0		13.5 S	16.4	176-20	2.6	13.0	43
Shot Smoky, Arc II								
0221	41.6	N of Indian Spring AFB on Indian Springs road	6.3 N	20.0	100-50	0.7	30.9 (S)	--
0222	--		4.5 N	21.2	104-55	0.8	2430 (S)	--
0223	36.4		1.4 N	23.2	110-40	0.9	9350 (S)	--
0224	35.3		-0-	24.2	112-40	1.0	10,100 (S)	--
0225	34.8		0.5 S	24.8	113-15	1.1	10,900 (S)	--
0201	34.0		1.0 S	25.4	113-35	1.1	8050	12
0202	32.7		2.0 S	26.8	114-50	1.1	5050	13
0203	31.2		3.2 S	27.9	117-15	1.2	640	30
0204	29.9		4.5 S	28.6	119-15	1.5	181	24
0205	28.6		5.9 S	30.0	121-35	2.0	66.6	49
0206	27.3		7.2 S	34.4	123-40	3.0	26.2	36
0207	26.1		8.5 S	31.0	126-00	3.5	30.4	41
0208	24.8		9.9 S	32.0	128-05	4.2	25.6	57
0209	23.4		11.1 S	32.7	129-35	4.5	16.6	77
0210	22.0		12.5 S	33.8	131-20	5.2	12.7	71

TABLE C. 1 (contd)

Sta. No.	Station Location		Miles from Midline	Miles from GZ	Bearing from GZ, deg-min	Fallout time, H + hour	Total β activity, μc/sq ft	Pct <44 micron fraction deposited
	Miles	Reference						
Shot Smoky, Arc II (contd)								
0211	20.6	N of Indian Spring AFB on Indian Springs road	14.0 S	34.9	133-25	7.0	8.49	77
0212	19.4		15.1 S	35.4	134-35	6.3	3.38	66
0213	18.1		16.5 S	36.4	136-20	6.5	6.65	96
0214	16.7		17.9 S	37.2	138-05	6.7	4.47	82
0215	15.4		19.2 S	38.1	139-20	7.1	3.45	96
0216	14.0		20.5 S	39.0	140-55	8.0	2.99	92
0217	12.7		21.8 S	40.0	142-10	8.2	3.41	99
0218	11.4		23.2 S	41.0	143-30	8.5	3.64	99
0219	10.1		24.5 S	42.0	144-40	8.7	0.70	98
0220	8.8		25.8 S	42.9	145-45	9.0	2.98	99
Shot Smoky, Arc III								
0325	53.2	N of U. S. 95 on Sheep Canyon road	7.8 N	49.0	099-00	2.5	34.4 (S)	--
0324	50.3		3.2 N	48.2	104-50	2.9	717 (S)	--
0321	48.1		1.0 N	48.2	107-35	3.1	5100 (S)	--
0301	47.1		-0-	48.1	108-45	3.2	8190	16
0322	47.0		0.1 S	48.1	108-50	3.2	6390 (S)	--
0302	45.1		1.9 S	47.9	111-25	3.3	1150	15
0303	43.2		3.9 S	48.0	113-50	3.5	244	37
0304	41.4		5.9 S	48.8	115-55	3.7	221	22
0305	39.4		7.8 S	50.0	117-45	3.9	180	30
0306	37.5		9.8 S	51.2	119-40	4.2	32.0	45
0307	35.5		11.4 S	51.5	121-40	4.4	23.8	58
0308	33.6		13.4 S	52.6	123-30	4.6	24.3	76
0309	31.6		15.3 S	53.7	125-25	5.0	14.3	78
0310	29.7		17.3 S	54.7	127-05	5.5	10.3	75
0311	27.7		19.3 S	55.0	129-15	6.0	11.0	59
0312	25.8		21.2 S	55.5	131-15	6.5	5.59	89
0313	23.8		23.1 S	56.2	133-15	7.0	2.69	85
0314	21.8		25.0 S	57.0	134-50	7.5	2.12	93
0315	19.9		27.0 S	58.0	136-45	8.0	0.56	88
0316	17.8		28.9 S	58.8	138-25	--	0.69	97
0317	15.7		31.1 S	59.8	140-05	--	0.76	98
0318	13.9		32.5	61.0	141-15	--	0.38	91
0319	11.9		34.1 S	62.9	141-15	--	0.53	89
0320	10.0		35.5 S	65.1	141-20	--	0.38	90
Shot Smoky, Arc IV-A								
0521	8.5	N of Kane Springs road on U. S. 93	6.0 N	59.7	096-25	3.2	62.0 (S)	--
0522	2.4		0.3 N	62.8	101-20	4.0	2000 (S)	--
0524	1.6		-0-	63.3	101-40	4.1	1440 (S)	--
0523	1.3		0.2 S	63.7	101-55	4.1	2770 (S)	--
0501	0		1.3 S	64.6	102-25	4.2	1260	30
0525	1.2	S of Kane Springs road on U. S. 93	2.8 S	64.9	103-35	4.4	2160 (S)	--
0502	2.3		3.7 S	65.3	104-25	4.4	78.3	64
0526	2.9		4.5 S	66.0	105-05	4.5	23.6 (S)	--
0503	4.2		5.5 S	66.6	105-50	4.6	63.1	38
0504	6.2		7.0 S	68.1	107-00	5.0	42.5	60
0527	7.2		8.2 S	68.9	107-50	5.2	1050 (S)	--
0505	8.2		8.8 S	69.5	108-15	5.2	38.7	48
0506	10.3		10.8 S	70.6	109-40	5.5	25.1	58
0507	12.3		12.5 S	72.1	110-55	5.7	32.3	56
0508	14.6		14.6 S	73.1	112-25	6.0	25.6	63
0509	16.3		15.0 S	75.0	112-15	6.2	27.8	63
0510	18.4		15.2 S	77.1	112-20	6.5	21.6	70
0511	20.4		16.1 S	79.1	112-35	6.8	17.9	65
0512	22.5		16.9 S	81.3	113-00	7.3	9.14	86
0513	24.6		17.3 S	83.5	113-10	7.7	14.1	80

TABLE C. 1 (contd)

Sta. No.	Station Location		Miles from Midline	Miles from GZ	Bearing from GZ, deg-min	Fallout time, H + hour	Total β activity, μc/sq ft	Pct <44 micron fraction deposited
	Miles	Reference						
Shot Smoky, Arc IV-A (contd)								
0514	26.4	S of Kane Springs road on U. S. 93	18.0 S	85.2	113-15	8.3	14.9	79
0515	28.5		18.8 S	87.2	113-35	8.5	15.5	81
0516	11.4	N of Overton on Nev. 12	19.2 S	93.6	112-35	8.5	NM	--
0517	9.4		21.2 S	94.8	113-15	8.7	14.7	94
0518	6.6		23.8 S	96.1	114-00	9.0	3.07	93
0519	4.6		25.6 S	98.6	114-55	9.5	1.81	96
0520	2.6		27.4 S	100.3	115-30	9.7	1.12	97
Shot Smoky, Arc IV-B								
0401	4.7	E of Pole-Line road on road to U. S. 93	16.0 S	73.3	113-35	6.0	16.3	78
0402	2.6		17.3 S	72.0	114-55	6.0	19.3	74
0403	0.6		19.0 S	71.2	116-35	6.0	17.4	85
0404	38.0	N of U. S. 93/91 on Pole-Line road	20.5 S	71.8	117-45	7.0	16.0	78
0405	36.0		22.5 S	72.9	119-05	7.0	18.7	83
0406	34.0		24.5 S	74.0	120-25	8.0	13.0	88
0407	31.9		25.3 S	75.0	120-50	8.0	12.4	91
0408	29.9		26.5 S	75.4	121-35	8.0	9.16	89
0409	27.7		28.3 S	76.5	122-45	8.0	7.67	93
0410	25.7		30.2 S	77.5	124-00	8.5	4.79	95
0411	23.7		32.0 S	78.0	125-10	8.5	6.58	67
0412	21.5		34.0 S	78.9	126-35	8.5	2.54	88
0413	19.5		35.5 S	79.8	127-40	9.0	1.51	96
Shot Smoky, Arc V								
0620	3.6	S of Kane Springs road on Morman Mesa road	12.5 N	92.2	091-30	3.9	7.37	41
0619	5.6		12.0 N	94.0	091-40	3.9	11.0	66
0618	7.6		11.0 N	95.5	092-10	4.0	14.5	41
0617	9.6		9.5 N	95.8	093-10	4.1	27.2	38
0616	11.6		8.0 N	96.8	094-00	4.1	79.1	35
0615	13.6		7.2 N	97.8	094-45	4.2	207	33
0614	15.6		4.4 N	98.9	095-40	4.3	373	34
0613	17.6		2.2 N	99.5	096-50	4.5	479	38
0612	19.4		0.5 N	99.4	097-55	4.5	643	38
0665	20.6	(Midline)	-0-	99.3	098-25	4.5	1280 (S)	--
0611	21.5		0.5 S	99.2	098-35	4.6	726	38
0644	22.0		1.1 S	99.2	099-15	4.6	419 (S)	--
0610	23.6		1.8 S	99.2	099-25	4.6	620	39
0609	25.6		3.3 S	99.8	100-20	4.7	496	35
0608	26.8		4.8 S	99.9	101-10	4.8	334	32
0654	28.6		5.2 S	99.8	101-30	4.8	320 (S)	--
0607	29.6		6.0 S	99.3	102-05	4.9	144	37
0606	31.6		7.0 S	98.9	102-55	4.9	62.6	45
0605	33.6		8.6 S	98.9	103-55	5.0	36.5	39
0604	35.6		10.2 S	99.1	104-45	5.2	23.8	57
0603	37.6		11.8 S	99.6	105-40	5.5	17.8	58
0602	39.6		13.2 S	100	106-35	5.8	16.2	52
0601	41.6		14.9 S	100	107-30	6.1	14.7	65
Shot Smoky, Arc VI								
0721	25.9	N of U.S. 91 on Utah 18	12.0 N	137	081-45	4.7	53.5 (S)	--
0722	14.4		4.0 N	134	086-00	4.8	259 (S)	--
0724	11.3	(First Midline)	-0-	136	088-55	4.8	316 (S)	--
0725	7.8		3.5 S	137	089-25	6.0	204 (S)	--
0731	32.8	S of Utah 18 on U. S. 91	8.1 S	122	097-05	5.4	41.4 (S)	--
0730	31.8		7.1 S	122	096-50	5.4	115 (S)	--
0729	11.0		2.0 N	129	089-25	4.7	535 (S)	--
0728	8.7	(Second Midline)	0-	130	089-35	5.0	667 (S)	--
0727	7.2		2.3 S	131	090-05	5.5	225 (S)	--
0726	4.1		5.0 S	132	090-30	5.5	122 (S)	--

TABLE C. 1 (contd)

Sta. No.	Station Location		Miles from Midline	Miles from GZ	Bearing from GZ, deg-min	Fallout time, H + hour	Total β activity, μc/sq ft	Pct <44 micron fraction deposited
	Miles	Reference						
Shot Smoky, Arc VI (contd)								
0901	0.7	S of Virgin River on Utah 64	11.9 S	140	092-10	8.1	18.9	71
0902	1.7		12.3 S	141	092-35	8.1	12.9	68
0903	2.8		12.7 S	141	093-05	8.2	15.4	83
0904	3.9		13.0 S	141	093-30	8.3	15.0	77
0905	5.0		13.5 S	141	094-00	8.4	14.6	84
0906	6.0		14.3 S	141	094-20	8.5	16.3	81
0907	7.1		15.1 S	141	094-45	8.6	17.1	72
0908	8.2		15.9 S	141	095-05	8.7	14.4	81
0909	9.2		16.8 S	141	095-35	8.8	13.1	85
0910	10.3		17.5 S	141	096-00	9.0	14.6	81
0911	11.4		18.3 S	141	096-25	9.1	13.0	91
0912	12.4		19.1 S	141	096-45	9.2	11.6	79
0913	13.5		20.2 S	141	097-05	9.4	10.4	81
0914	14.6		20.9 S	142	097-25	9.6	9.66	78
0915	15.6		21.5 S	142	097-40	9.7	8.93	83
0916	16.7		22.6 S	142	098-00	9.9	7.88	79
0917	17.8		23.7 S	142	098-30	10.0	7.31	77
0918	18.9		24.8 S	142	099-00	10.2	7.37	81
0919	20.1		25.9 S	142	099-25	10.5	7.67	80
0920	21.2		26.0 S	142	099-55	10.7	5.67	81
0921	37.0		30.4 S	145	100-25	11.5	8.38 (S)	--
Shot Smoky, Arc VII								
0825	7.6	S of Utah 14 on U. S. 91	9.5 N	164	078-35	5.4	49.1 (S)	--
0820	14.4		5.0 N	161	080-45	5.5	84.2	48
0819	16.5		4.0 N	160	081-20	5.5	89.1	48
0818	18.3		2.5 N	160	082-00	5.5	145	48
0817	20.3		1.3 N	159	082-40	5.6	207	52
0824	21.9		0.7 N	158	082-50	5.6	457 (S)	--
0816	22.3	(Midline)	-0-	158	083-10	5.6	201	45
0815	24.2		1.5 S	158	083-50	5.6	217	47
0823	25.0		2.0 S	158	084-05	5.8	316 (S)	--
0814	26.2		2.5 S	157	084-25	5.8	212	42
0813	28.1		4.0 S	156	085-05	6.0	179	47
0821	30.1		5.1 S	155	085-45	6.0	197	49
0811	32.1		6.8 S	154	086-20	6.0	193	50
0810	33.9		7.5 S	153	087-00	6.5	182	52
0809	36.2		8.0 S	152	087-35	6.5	170	64
0808	37.1		8.3 S	151	087-50	6.7	158	51
0807	39.9		9.1 S	149	088-45	6.7	102	48
0806	41.9		10.5 S	148	089-25	7.0	61.9	52
0822	42.0		11.6 S	148	089-30	7.0	122 (S)	--
0805	43.8		11.1 S	147	089-55	7.5	41.4	64
0804	45.8		11.3 S	146	090-10	7.5	32.7	61
0821	47.3		11.6 S	145	090-30	7.5	26.5 (S)	--
0803	47.8		11.3 S	143	090-45	7.5	17.2	83
0802	49.7		10.5 S	142	090-50	7.5	22.3	67
0801	51.7		10.4 S	140	091-15	7.0	31.4	72
Shot Smoky, Arc VIII								
1021	28.3	N of Panguitch on U. S. 89	20.2 N	223	070-10	12.5	31.3 (S)	--
1022	24.0		20.0 N	219	070-40	12.5	93.3 (S)	--
1023	12.5		12.5 N	212	073-00	12.5	179 (S)	--
1024	8.9		10.0 N	209	073-45	12.5	129 (S)	--
1025	1.4		3.0 N	206	073-35	12.5	250 (S)	--
1026	3.3		1.0 S	207	076-45	12.0	195 (S)	--
1027	7.7		5.0 S	208	077-45	12.0		
1028	8.1		5.5 S	207	078-00	12.0	53.5 (S)	--
1020	23.7		13.0 S	201	081-15	12.0	1.65	92

TABLE C. 1 (concl)

Sta. No.	Station Location		Miles from Midline	Miles from GZ	Bearing from GZ, deg-min	Fallout time, H + hour	Total β activity, μc/sq ft	Pct <44 micron fraction deposited
	Miles	Reference						
Shot Smoky, Arc VIII (concl)								
1015	35.2	N of Panguitch on U. S. 89	19.0 S	196	084-10	12.0	1.47	99
1010	46.9		23.8 S	191	086-40	12.0	2.81	96
1005	59.4		32.2 S	194	089-10	12.5	0.13	93
1001	67.9		40.0 S	197	091-05	13.5	1.14	93

APPENDIX D

RESULTS OF RADIONUCLIDE ANALYSES OF FALLOUT DEBRIS ORIGINATING FROM FIVE SHOTS: BOLTZMANN, PRISCILLA, DIABLO, SHASTA AND SMOKY

TABLE D.1 Radionuclide Analysis of Fractions from Fallout Debris from Five Shots

NS Not Significant

Size Range of Fraction, microns	Radionuclide at D + 30 Days							Percent of Total Beta Activity (Σ)
	Ba^{140}	$Ce^{141} + Ce\text{-}Pr^{144}$	Cs^{136}	$Ru^{103, 106}$	$Sr^{89, 90}$	Y^{91}	Zr^{95}	
	Pct of Total Beta Activity							
Shot Boltzmann								
Arc I 36 mi. from GZ, 0.0 mi. from midline, Fallout time H + 1.4 hr. (Sta. No. 0111)								
125 - 149	13.9	20.9	0.2	2.8	1.3	8.7	10.5	58.4
<44	15.3	16.1	0.2	8.2	2.2	10.5	8.0	60.4
Arc II 48 mi. from GZ, 0.7 mi. E of midline, Fallout time H + 2.0 hr. (Sta. No. 0308)								
125 - 149	15.5	20.1	0.2	2.9	1.6	9.4	9.5	59.4
<44	15.4	15.8	0.2	6.3	2.5	10.9	8.3	59.5
Arc III 79 mi. from GZ, 0.8 mi. W of midline, Fallout time H + 3.6 hr. (Sta. No. 0504)								
88 - 105	17.0	21.8	0.3	4.6	1.9	10.6	7.8	63.9
44 - 88	14.5	17.7	0.2	3.4	1.6	9.1	9.1	55.6
<44	14.6	18.2	0.3	5.6	3.9	9.6	7.9	60.2
Shot Priscilla								
Arc I 18 mi. from GZ, 1.9 mi. N of midline, Fallout time H + 2.4 hr. (Sta. No. 0115)								
350 - 500	18.6	15.5	0.1	5.8	3.1	17.4	4.0	64.6
297 - 350	17.2	17.2	0.09	6.4	2.7	15.0	6.2	64.7
250 - 297	18.5	16.9	0.08	5.4	2.5	16.6	3.5	63.5
210 - 297	18.5	16.9	0.08	5.4	2.5	16.6	3.5	63.5
177 - 210	20.0	18.6	0.09	4.0	2.5	16.2	2.5	64.1
149 - 177	19.8	20.0	0.08	3.6	2.7	17.2	2.5	65.9
125 - 149	20.2	14.9	0.09	5.0	2.7	16.6	2.7	62.2
105 - 125	18.5	16.3	NS	4.6	3.1	15.3	6.3	64.1
88 - 105	18.1	15.0	0.07	4.4	3.5	12.1	4.8	58.0
44 - 88	18.0	11.3	0.03	6.0	3.8	8.7	5.6	53.3
<44	18.4	13.3	0.09	8.7	5.8	14.5	3.5	64.2
Arc II 55 mi. from GZ, 0.1 mi. N of midline, Fallout time H + 3.9 hr. (Sta. No. 0217)								
149 - 177	15.1	16.2	0.07	12.7	2.8	11.4	3.8	62.2
125 - 149	14.6	16.1	0.05	13.0	2.7	11.7	2.8	60.8
105 - 125	15.9	14.1	0.07	9.8	2.7	12.6	3.2	58.4
88 - 105	16.9	14.7	0.1	9.6	2.7	13.1	2.8	60.0
44 - 88	18.0	13.4	0.07	10.3	3.6	15.1	4.3	64.9
<44	20.9	15.3	0.1	12.6	6.7	16.2	4.3	70.1
Arc III 68 mi. from GZ, 0.2 mi. S of midline, Fallout time H + 4.4 hr. (Sta. No. 0712)								
88 - 105	15.9	14.9	NS	11.4	2.5	15.5	2.8	63.1
44 - 88	19.4	14.7	NS	6.8	2.5	13.9	1.7	59.2
<44	20.2	16.3	0.12	11.3	7.2	10.5	4.4	70.1
Arc IV 126 mi. from GZ, 1.0 mi. S of midline, Fallout time H + 7.0 hr. (Sta. No. 1002)								
44 - 88	16.1	14.1	NS	11.5	3.5	19.2	3.6	67.9
<44	18.9	13.9	0.09	12.9	6.4	14.2	[illegible]	70.9
Arc V 152 mi. from GZ, 1.0 mi. S of midline, Fallout time H + 8.6 hr. (Sta. No. 0409)								
<44	16.1	11.3	0.08	10.5	6.0	12.2	3.9	60.0
Arc VI 188 mi. from GZ, 0.0 mi. S of midline, Fallout time H + 9.5 hr. (Sta. No. 0510)								
44 - 88	15.3	12.3	NS	12.2	5.2	11.4	3.4	59.8
<44	16.9	10.3	0.08	10.2	6.6	13.4	3.9	61.4

TABLE D.1 Radionuclide Analysis of Fractions from Fallout Debris from Five Shots (contd)

Size Range of Fraction, microns	Radionuclide at D + 30 Days							Percent of Total Beta Activity (Σ)
	Ba^{140}	Ce^{141} + $Ce\text{-}Pr^{144}$	Cs^{136}	$Ru^{103, 106}$	$Sr^{89, 90}$	Y^{91}	Zr^{95}	
	Pct of Total Beta Activity							
Shot Diablo								
Arc I 16 mi. from GZ, 6.7 mi. E of midline, Fallout time H + 3.2 hr. (Sta. No. 0118)								
149 - 177	13.7	16.8	0.16	2.0	1.5	11.1	7.6	52.8
125 - 149	14.3	16.8	0.16	1.6	1.6	11.0	8.8	54.3
105 - 125	12.9	15.7	0.16	1.3	1.3	9.4	10.6	51.3
88 - 105	10.6	15.9	0.09	1.3	1.1	8.0	12.5	49.6
44 - 88	13.1	13.5	0.15	1.7	1.5	10.1	8.3	48.4
<44	15.0	15.8	0.15	3.1	2.5	12.1	7.9	56.5
Arc II 20 mi. from GZ, 8.8 mi. S of midline, Fallout time H + 3.6 hr. (Sta. No. 0201)								
297 - 350	12.5	17.0	0.15	1.5	1.2	8.7	8.6	49.6
250 - 297	12.5	Lost	0.15	1.5	1.3	9.1	8.2	--
210 - 250	12.5	19.0	0.16	1.2	1.3	9.2	8.2	51.6
177 - 210	14.1	18.6	0.15	1.3	1.5	9.5	8.8	54.0
149 - 177	11.9	13.9	0.15	1.2	1.3	9.1	9.1	46.8
125 - 149	12.3	12.9	0.15	1.3	1.3	9.4	8.4	45.8
105 - 125	13.1	19.0	0.16	1.7	1.5	11.8	5.4	52.7
88 - 105	14.6	23.2	0.17	1.3	1.6	11.9	11.3	64.1
44 - 88	11.7	24.0	0.12	1.2	1.2	9.2	11.7	59.1
<44	14.9	18.8	0.15	2.8	2.4	11.4	8.2	58.6
Arc III 40 mi. from GZ, 0.8 mi. E of midline, Fallout time H + 5.1 hr. (Sta. No. 0314)								
44 - 88	13.7	21.7	0.17	1.6	1.6	12.1	9.4	60.2
<44	14.9	19.3	0.16	2.8	2.1	11.7	8.6	59.5
Arc IV 60 mi. from GZ, 20 mi. E of midline, Fallout time H + 6.7 hr. (Sta. No. 0501)								
44 - 88	13.8	15.1	0.21	1.7	1.5	10.9	7.2	50.5
<44	13.4	14.5	0.16	2.5	2.1	10.9	6.8	50.4
Shot Shasta								
Arc E II 25 mi. from GZ, 17.5 mi. E of midline, Fallout time H + 2.7 hr. (Sta. No. 0401)								
177 - 210	11.3	18.1	NS[a]	1.2	1.1	8.7	8.6	48.9
149 - 177	9.9	17.6	NS	0.8	1.1	8.0	8.8	46.2
125 - 149	9.4	16.5	NS	0.7	0.8	11.5	10.6	49.4
105 - 125	8.3	19.4	NS	0.7	0.5	--	13.7	--
88 - 105	13.7	15.3	NS	0.9	1.1	9.8	7.1	47.8
44 - 88	14.6	18.1	NS	1.9	1.5	10.5	7.4	53.9
<44	18.0	19.6	NS	3.4	4.2	10.6	7.8	63.4
Arc NS I 15 mi. from GZ, 1.3 mi. W of midline, Fallout time H + 0.7 hr. (Sta. No. 0701)								
250 - 297	12.7	17.0	NS	1.1	1.2	9.5	7.6	49.2
210 - 250	13.0	15.1	NS	1.1	1.2	9.6	7.8	47.8
177 - 210	14.3	17.3	NS	0.9	1.5	10.6	9.0	53.6
149 - 177	12.6	22.4	NS	0.9	1.2	10.6	9.9	57.6
125 - 149	9.1	23.7	NS	0.7	0.7	6.7	10.5	51.3
105 - 125	--	16.5	NS	1.5	1.1	9.2	7.2	--
88 - 105	14.5	15.0	NS	1.6	1.1	9.8	9.6	51.6
44 - 88	13.8	15.5	NS	1.9	1.2	10.3	6.2	49.9
<44	13.0	13.5	NS	2.7	1.9	10.2	6.6	47.8
< 5	--	13.7	NS	2.4	2.5	10.1	6.6	--
Arc NS I 25 mi. from GZ, 4.0 mi. E of midline, Fallout time H + 1.6 hr. (Sta. No. 0709)								
350 - 500	12.9	14.9	NS	1.2	1.3	8.7	10.3	49.3
297 - 350	8.8	16.9	NS	0.9	1.9	8.4	11.0	48.0
250 - 297	8.8	14.7	NS	0.9	0.9	8.4	8.0	41.9
210 - 250	12.3	14.5	NS	0.9	0.9	8.4	6.7	43.8
177 - 210	12.9	16.3	NS	1.1	1.1	9.5	7.2	48.1

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[a] Notations in this column throughout the remainder of this table are for both Cs^{136} and Cs^{137}.

TABLE D.1 Radionuclide Analysis of Fractions from Fallout Debris from Five Shots (contd)

Size Range of Fraction, microns	Radionuclide at D + 30 Days							Percent of Total Beta Activity (Σ)
	Ba^{140}	Ce^{141} + $Ce\text{-}Pr^{144}$	$Cs^{136,137}$	$Ru^{103,106}$	$Sr^{89,90}$	Y^{91}	Zr^{95}	
	Pct of Total Beta Activity							
Shot Shasta (contd)								
149 - 177	12.9	13.9	NS	1.5	1.2	8.7	6.7	44.9
125 - 149	12.6	15.5	NS	1.3	1.3	10.9	7.1	48.8
105 - 125	11.5	18.8	NS	0.9	0.1	9.1	7.9	48.4
88 - 105	10.6	18.6	NS	0.9	0.1	8.6	8.8	47.7
44 - 88	11.0	16.9	NS	1.5	0.9	7.4	7.2	44.9
<44	15.9	15.5	NS	3.4	0.1	11.4	7.0	53.3
Arc NS I: 34 mi. from GZ, 3.8 mi. E of midline; Fallout time H + 2.3 hr. (Sta. No. 0715)								
210 - 250	--	22.2	NS	1.3	1.6	8.7	6.7	--
177 - 210	17.6	14.1	NS	0.9	1.6	10.7	7.5	52.4
149 - 177	--	10.2	NS	0.3	0.8	7.1	4.2	--
125 - 149	16.1	16.5	NS	2.3	1.6	10.1	5.9	52.4
105 - 125	14.3	14.7	NS	1.9	1.5	7.6	7.4	47.4
88 - 105	14.3	16.5	NS	1.9	1.6	9.6	6.3	50.3
44 - 88	11.5	17.8	NS	1.2	1.2	8.6	8.3	48.6
<44	14.2	13.0	NS	3.5	2.3	9.4	6.4	48.8
< 5	19.8	6.2	NS	3.5	2.5	9.0	6.0	47.0
Arc NS I: 42 mi. from GZ, 2.5 mi. E of midline; Fallout time H + 3.0 hr. (Sta. No. 0720)								
350 - 500	14.2	14.6	NS	1.2	1.6	11.5	6.4	49.6
297 - 350	--	--	NS	--	1.6	12.1	7.1	--
250 - 297	--	13.8	NS	0.4	1.9	8.8	7.9	--
210 - 250	12.1	14.7	NS	0.4	1.7	10.1	8.0	47.0
177 - 210	--	16.3	NS	0.5	1.2	10.7	6.7	--
149 - 177	15.3	17.0	NS	0.5	1.3	11.3	8.4	53.9
125 - 149	15.9	14.7	NS	1.3	1.5	9.9	6.4	49.8
105 - 125	15.4	15.8	NS	0.5	1.5	9.1	7.4	49.7
88 - 105	14.5	12.5	NS	1.9	1.6	10.2	5.0	45.6
44 - 88	11.9	17.6	NS	1.3	1.2	9.2	7.4	48.6
<44	14.1	14.3	NS	2.8	2.3	11.0	4.8	49.3
< 5	--	10.7	NS	1.5	3.4	8.7	6.4	--
Arc N I: 35 mi. from GZ, 7.0 mi. W of midline; Fallout time H + 1.4 hr. (Sta. No. 0620)								
44 - 88	--	--	NS	--	1.1	--	--	--
<44	--	16.3	NS	--	2.3	12.5	6.0	--
Arc N I: 32 mi. from GZ; 1.0 mi. W of midline; Fallout time H + 1.7 hr. (Sta. No. 0617)								
350 - 500	10.3	17.0	NS	0.8	1.1	9.8	6.7	45.7
297 - 350	18.2	15.3	NS	0.8	1.1	8.6	6.8	50.8
250 - 297	--	17.6	NS	0.5	1.2	8.4	6.7	--
210 - 250	--	15.7	NS	0.1	1.7	10.3	6.2	--
177 - 210	11.7	14.1	NS	0.9	1.1	8.0	7.5	43.3
149 - 177	13.4	15.0	NS	0.9	1.2	9.6	6.4	46.6
125 - 149	16.9	15.4	NS	1.2	1.2	9.4	6.2	50.3
105 - 125	14.9	13.0	NS	1.5	1.3	10.2	5.2	46.1
88 - 105	10.7	18.6	NS	0.8	1.1	9.6	6.6	47.4
44 - 88	10.6	17.3	NS	0.7	0.8	7.4	7.6	44.4
< 44	13.3	14.5	NS	2.8	1.9	10.3	6.0	48.8
Arc N I: 41 mi. from GZ, 33 mi. E of midline; Fallout time H + 4.1 hr. (Sta. No. 0505)								
< 44	16.2	12.3	NS	2.8	4.7	9.4	5.5	50.9
Arc N II: 47 mi. from GZ, 13.2 mi. W of midline; Fallout time H + 2 hr. (Sta. No. 0806)								
< 44	--	16.3	NS	3.4	3.6	11.9	7.1	--

TABLE D. 1 Radionuclide Analysis of Fractions from Fallout Debris from Five Shots (contd)

Size Range of Fraction, microns	Ba^{140}	Ce^{141} + $Ce\text{-}Pr^{144}$	$Cs^{136,137}$	$Ru^{103,106}$	$Sr^{89,90}$	Y^{91}	Zr^{95}	Percent of Total Beta Activity (Σ)
	Pct of Total Beta Activity							
Shot Shasta (contd)								
Arc N II· 44 mi. from GZ, 1.1 mi. W of midline, Fallout time H + 2.8 hr. (Sta. No. 0815)								
250 - 297	--	16.9	NS	1.1	1.2	8.0	--	--
210 - 250	--	16.9	NS	1.3	1.9	11.1	7.2	--
177 - 210	--	15.7	NS	1.7	1.6	9.6	9.0	--
149 - 177	9.9	13.4	NS	1.2	1.6	9.9	7.5	43.6
125 - 149	14.6	15.1	NS	1.9	1.6	10.5	6.2	49.8
105 - 125	17.3	16.1	NS	1.7	1.5	10.7	6.4	53.7
88 - 105	10.2	10.9	NS	1.3	1.1	7.9	4.3	35.6
44 - 88	12.2	16.6	NS	1.3	1.2	10.5	8.3	50.1
< 44	14.5	15.5	NS	3.2	2.1	10.9	6.7	53.2
< 5	--	15.4	NS	1.3	2.7	10.3	7.2	--
Arc N II 44 mi. from GZ, 5.5 mi. E of midline, Fallout time H + 3.6 hr. (Sta. No. 0902)								
88 - 105	--	18.6	NS	3.6	3.5	13.0	6.4	--
44 - 88	13.5	17.0	NS	1.5	1.5	10.1	6.7	50.3
< 44	14.6	16.6	NS	2.1	2.5	10.9	6.8	53.6
< 5	--	16.6	NS	2.5	5.9	10.6	6.7	--
Arc N II. 45 mi. from GZ; 13 mi. E of midline, Fallout time H + 4.7 hr. (Sta. No. 0910)								
88 - 105	18.8	14.1	NS	3.1	2.7	12.1	5.6	56.3
44 - 88	12.6	14.3	NS	1.3	1.6	8.8	6.0	44.8
< 44	15.8	14.5	NS	2.5	2.5	12.9	6.2	54.4
< 5	--	--	NS	2.9	6.2	14.5	6.4	--
Arc N II 43 mi. from GZ, 17.8 mi. E of midline, Fallout time H + 4.8 hr. (Sta. No. 0915)								
88 - 105	--	13.0	NS	1.2	2.9	10.7	7.0	--
44 - 88	14.3	16.2	NS	1.2	1.3	9.2	6.6	48.9
< 44	14.1	13.1	NS	2.3	2.8	10.9	5.8	48.9
Arc N III: 81 mi. from GZ, 4.3 mi. W of midline, Fallout time H + 5.2 hr. (Sta. No. 1001)								
44 - 88	--	18.9	NS	1.6	1.5	9.5	9.4	--
< 44	--	15.4	NS	2.4	2.8	11.4	6.3	--
Shot Smoky								
Arc I· 4.6 mi. from GZ, 4.7 mi. S of midline, Fallout time H + 0.2 hr. (Sta. No. 0105)								
500 -1000	15.1	20.4	NS	0.5	0.9	7.4	--	--
350 - 500	8.7	26.4	NS	1.2	0.9	7.8	6.8	51.9
297 - 350	8.6	18.8	NS	1.5	0.9	8.3	8.6	46.6
250 - 297	7.9	21.6	NS	1.1	0.9	--	7.9	--
210 - 250	9.6	20.1	NS	1.2	1.1	9.8	8.0	49.8
177 - 210	8.4	15.1	NS	1.3	0.9	9.5	9.2	44.6
149 - 177	7.5	23.6	NS	1.1	0.9	8.2	8.4	49.7
125 - 149	7.1	18.6	NS	0.5	0.8	8.0	8.0	43.1
105 - 125	9.8	20.6	NS	1.6	1.1	9.4	6.8	49.3
88 - 105	10.2	24.5	NS	1.6	1.3	11.5	9.1	58.3
44 - 88	11.8	21.7	NS	1.7	1.3	11.4	8.0	56.0
< 44	13.9	16.6	NS	2.1	2.4	12.1	5.9	53.1
< 5	16.8	21.3	NS	2.7	3.2	13.0	6.7	63.9
Arc II. 25 mi. from GZ, 1.0 mi. S of midline, Fallout time H + 1.1 hr. (Sta. No. 0201)								
500 -1000	8.7	17.3	NS	0.9	1.2	7.0	8.2	43.3
350 - 500	10.6	18.8	NS	1.2	1.2	9.8	7.6	49.2
297 - 350	11.3	19.6	NS	1.3	1.3	--	8.2	--
250 - 297	10.3	23.9	NS	1.2	1.2	10.1	6.8	53.5
210 - 250	10.6	21.8	NS	1.2	1.2	9.8	10.2	54.8
177 - 210	2.1	23.9	NS	1.5	1.2	9.9	10.9	49.4
149 - 177	10.7	20.1	NS	0.8	1.3	11.1	10.5	54.5

TABLE D.1 Radionuclide Analysis of Fractions from Fallout Debris from Five Shots (contd)

Size Range of Fractions, microns	Radionuclide at D + 30 Days							Percent of Total Beta Activity
	Ba^{140}	Ce^{141} + $Ce\text{-}Pr^{144}$	$Cs^{136,137}$	$Ru^{103,106}$	$Sr^{89,90}$	Y^{91}	Zr^{95}	(Σ)
	Pct of Total Beta Activity							
Shot Smoky (contd)								
125 - 149	9.8	19.3	NS	1.3	1.2	9.6	10.3	51.6
105 - 125	8.7	19.7	NS	1.2	1.1	9.5	9.0	49.2
88 - 105	11.0	15.8	NS	1.3	1.5	10.5	6.3	46.4
44 - 88	11.9	15.0	NS	1.2	1.6	10.7	6.0	46.5
< 44	12.9	14.9	NS	1.9	2.7	14.1	5.8	52.1
< 5	--	18.4	NS	1.3	2.8	11.5	12.2	--
Arc III: 48 mi. from GZ, 0.0 mi. from midline; Fallout time H + 3.2 hr. (Sta. No. 0301)								
500 -1000	11.4	16.3	NS	1.2	1.6	15.0	7.4	52.9
350 - 500	10.7	19.4	NS	1.9	1.3	10.6	8.0	52.0
297 - 350	9.9	16.6	NS	1.2	1.2	9.5	7.8	46.2
250 - 297	15.4	22.8	NS	1.9	1.9	13.1	8.2	63.2
210 - 250	11.3	15.5	NS	1.2	1.5	9.5	6.7	46.0
177 - 210	12.5	20.2	NS	1.2	1.3	11.9	7.9	55.1
149 - 177	12.1	20.2	NS	1.5	1.5	11.4	7.9	54.5
125 - 149	11.9	22.5	NS	1.5	1.3	11.0	9.1	57.4
105 - 125	10.5	18.8	NS	1.3	1.2	10.7	9.6	52.1
88 - 105	9.2	18.5	NS	1.2	1.1	8.4	8.4	46.9
44 - 88	11.5	15.8	Ns	1.3	1.5	10.7	6.0	46.9
< 44	15.4	17.2	NS	1.7	2.8	12.3	7.4	46.8
< 5	13.3	14.5	NS	1.6	2.9	8.7	6.7	47.7
Arc IV: 65 mi. from GZ, 1.3 mi. S of midline; Fallout time H + 4.2 hr. (Sta. No. 0501)								
177 - 210	12.3	16.6	NS	1.9	1.6	17.4	6.4	56.3
149 - 177	14.6	17.7	NS	1.1	1.7	14.9	5.6	55.6
125 - 149	13.4	17.7	NS	0.9	1.5	12.7	5.6	51.9
105 - 125	11.7	16.9	NS	1.1	1.3	8.7	8.3	51.9
88 - 105	10.9	18.6	NS	0.9	1.2	9.6	4.3	45.6
44 - 88	10.1	18.1	NS	0.9	1.2	10.6	6.3	47.2
< 44	13.8	17.4	NS	1.9	2.4	15.4	6.7	57.6
< 5	12.5	15.0	NS	1.7	2.8	13.9	6.3	52.3
Arc V: 99 mi. from GZ, 0.5 mi. S of midline, Fallout time H + 4.6 hr. (Sta. No. 0611)								
177 - 210	12.1	--	NS	1.3	2.3	--	6.6	--
149 - 177	12.9	14.9	NS	3.8	3.6	--	5.6	--
125 - 149	19.0	17.2	NS	2.4	2.4	14.1	1.6	56.7
105 - 125	15.9	13.5	NS	2.1	2.1	15.3	4.3	53.3
88 - 105	15.5	14.1	NS	1.3	1.7	12.5	5.1	50.3
44 - 88	11.8	18.0	NS	1.1	1.5	9.5	7.9	49.7
< 44	14.5	15.8	NS	2.1	2.5	11.5	6.8	53.3
< 5	16.2	14.6	NS	1.6	3.1	--	6.3	--
Arc VII: 158 mi. from GZ; 0.0 mi. from midline; Fallout time H + 5.6 hr. (Sta. No. 0816)								
210 - 250	10.6	26.5	NS	1.1	2.7	5.9	11.1	57.9
177 - 210	--	--	NS	3.8	2.9	11.7	8.6	--
149 - 177	--	7.9	NS	8.2	5.1	24.8	6.4	--
125 - 149	16.8	18.2	NS	1.2	3.2	21.6	6.3	67.3
105 - 125	14.7	21.0	NS	1.6	2.4	5.6	8.0	53.5
88 - 105	12.5	19.6	NS	1.1	3.2	13.4	5.1	54.8
44 - 88	13.5	24.9	NS	1.3	1.9	11.3	5.6	58.6
< 44	15.5	15.4	NS	2.4	3.2	14.5	5.5	56.5
< 5	20.2	14.9	NS	1.3	3.5	--	5.9	--

APPENDIX E

PERCENT OF BETA ACTIVITY MAGNETICALLY SEPARATED FROM SEVEN SIZE FRACTIONS (Table E. 1)

SOLUBILITY IN WATER AND ACID OF MAGNETIC AND NONMAGNETIC FRACTIONS FROM FALLOUT MATERIAL (Table E. 2)

TABLE E.1 Percent of Beta Activity Magnetically Separated from Seven Size Fractions

ND, not determined. NA, no sample available for analysis.

Sta. No.	Miles from GZ	Miles from Midline	Fallout Time, H + hr	Size Fraction, microns						
				<44	44-88	88-105	105-125	125-149	149-177	177-210
				Pct of Activity						
Shot Boltzmann (500 ft Tower, 12 kt)										
0120	38.0	6.2 W	2.9	18	ND	ND	ND	ND	ND	ND
0118	35.9	5.2 W	2.7	ND	ND	92	ND	ND	ND	ND
0116	35.6	4.6 W	2.3	ND	ND	ND	80	ND	ND	ND
0113	36.3	2.0 W	1.6	ND	24	89	95	97	84	63
0111	36.3	0.0	1.4	ND	ND	ND	ND	ND	91	ND
0108	35.0	2.3 E	1.6	7	69	52	60	87	63	92
0107	34.5	3.2 E	1.7	2	83	64	47	83	57	95
0101	34.0	9.2 E	4.2	15	ND	ND	ND	ND	ND	ND
0302	50.4	5.1 W	2.5	4	88	78	73	20	29	ND
0303	50.0	4.2 W	2.4	12	85	87	39	82	50	36
0307	48.3	0.5 W	2.1	ND	39	86	91	82	60	NA
0509	80.8	10.6 W	3.8	15	85	NA	NA	NA	NA	NA
0505	79.0	3.6 W	3.7	ND	90	68	NA	NA	NA	NA
0502	78.0	3.0 E	3.9	14	87	NA	NA	NA	NA	NA
Shot Priscilla (700 ft Balloon, 37 kt)										
No significant magnetically separated fractions found in 24 different size fractions analyzed, <0.2 pct.										
Shot Hood (1500 ft Balloon, 74 kt)										
No significant magnetically separated fractions found in seven <44 micron size fractions analyzed, <0.1 pct.										
Shot Diablo (500 ft Tower, 17 kt)										
0119	15.3	6.3 N	3.1	4	55	91	87	Samples NA for >125 micron fractions for Shot Diablo		
0202	20.3	10.0 S	3.5	7	88	80	NA			
0312	40.0	3.9 N	5.1	9	76	NA	NA			
0502	5.9	21.5 S	6.7	18	71	NA	NA			
Shot Shasta (500 ft Tower, 17 kt)										
0306	10.7	9.0 E	1.2	10	67	ND	ND	NA	NA	NA
0304	23.6	17.0 E	2.5	5	NA	NA	NA	NA	NA	NA
0405	29.0	19.0 E	3.1	23	83	57	NA	NA	NA	NA
0408	18.5	18.5 E	1.6	6	NA	NA	NA	NA	NA	NA
0620	34.5	7.0 W	1.4	47	60	NA	NA	NA	NA	NA
0618	32.1	2.9 W	1.5	3	88	77	62	NA	NA	NA
0617	32.3	1.0 W	1.7	18	97	74	37	39	45	43
0616	31.5	1.0 E	1.8	17	64	54	38	NA	NA	NA
0612	31.1	8.0 E	2.4	2	31	?	10	22	NA	NA
0610	32.5	10.4 E	2.9	7	68	41	32	41	NA	NA
0606	34.3	17.0 E	3.6	16	52	14	NA	NA	NA	NA
0511	37.3	20.3 E	3.9	3	NA	NA	NA	NA	NA	NA
0801	51.3	19.8 W	1.8	8	71	NA	NA	NA	NA	NA
0808	45.5	10.5 W	2.2	19	71	NA	NA	NA	NA	NA
0814	43.8	3.8 W	2.7	9	82	26	NA	NA	NA	NA
0815	43.6	1.1 W	2.8	5	76	NA	NA	NA	NA	NA
0816	43.5	0.0	2.9	6	78	52	55	NA	NA	NA
0902	43.9	5.5 E	3.6	7	53	NA	NA	NA	NA	NA
0907	44.3	10.3 E	4.3	78	58	NA	NA	NA	NA	NA
0908	44.9	11.1 E	4.5	4	64	NA	NA	NA	NA	NA
0909	45.1	12.1 E	4.7	22	66	NA	NA	NA	NA	NA
0915	43.4	17.8 E	4.8	12	42	1	NA	NA	NA	NA
Shot Smoky (700 ft Tower, 44 kt)										
See Table E.2 for results.										

TABLE E. 2 Solubility in Water and Acid of Magnetic and Nonmagnetic Fractions From Fallout Material

Acid used, 0.1 N HCl, see Appendix A for procedure. ND, not determined. NS, not significant (< 0.1 pct).

						Solubility					
						Magnetic			Nonmagnetic		
Sta. No.	Miles from GZ	Miles from Midline	Fallout Time, H + hr	Size Range, microns	Pct Magnetic Fraction	H_2O	HCl	Total	H_2O	HCl	Total
						Pct of beta activity					
Shot Boltzmann (500 ft Tower, 12 kt)											
0120	38.0	6.2 W	2.9	< 44	17.9	0.9	39.9	40.8	ND	ND	--
0118	35.9	5.2 W	2.7	88-105	92.0	0.3	5.7	6.0	ND	ND	--
0113	36.3	2.0 W	1.6	125-149	97.0	0.3	4.7	5.0	ND	ND	--
0111	36.3	0.0	1.4	149-177	91.0	0.3	4.7	5.0	ND	ND	--
0107	34.5	3.2 E	1.7	177-210	95.4	0.2	3.6	3.8	ND	ND	--
0302	50.4	5.1 W	2.5	105-125	73.0	0.8	4.2	5.0	ND	ND	--
				88-105	78.0	0.6	15.4	16.0	ND	ND	--
				44- 88	88.0	1.7	6.7	8.4	ND	ND	--
				< 44	3.7	1.4	28.0	29.4	ND	ND	--
0307	48.3	0.5 W	2.1	125-149	81.9	0.4	4.8	5.2	ND	ND	--
0505	79.0	3.6 W	3.7	88-105	68.3	0.9	4.6	5.5	ND	ND	--
				44- 88	90.4	0.3	6.2	6.5	ND	ND	--
Shot Priscilla (700 ft Balloon, 37 kt)											
0115	18.4	1.9 N	2.4	350-500	NS	--	--	--	30.6	59.7	90.3
				297-350	NS	--	--	--	32.0	54.0	86.0
				250-297	NS	--	--	--	11.7	48.7	60.4
				210-250	NS	--	--	--	16.9	59.0	75.9
0115	18.4	1.9 N	2.4	177-210	NS	--	--	--	14.0	49.4	63.4
				149-177	NS	--	--	--	11.5	52.0	63.5
				125-149	NS	--	--	--	11.6	52.0	63.6
				105-125	NS	--	--	--	11.6	54.2	65.8
				88-105	NS	--	--	--	10.5	57.1	67.6
				44- 88	NS	--	--	--	18.5	52.6	71.1
				< 44	NS	--	--	--	13.2	53.9	67.1
0216	55.5	1.0 N	3.9	125-149	NS	--	--	--	18.9	49.9	68.8
				105-125	NS	--	--	--	15.2	54.0	69.2
				88-105	NS	--	--	--	15.1	49.4	64.5
				44- 88	NS	--	--	--	20.2	32.9	53.1
				< 44	NS	--	--	--	12.5	46.9	59.4
0710	69.3	0.4 N	5.0	88-105	NS	--	--	--	13.0	53.8	66.8
				44- 88	NS	--	--	--	11.5	48.8	60.3
1002	126	1.1 S	7.1	44- 88	NS	--	--	--	18.2	48.3	66.5
				< 44	NS	--	--	--	12.6	50.4	63.0
0409	152	1.1 S	8.6	44- 88	NS	--	--	--	14.4	57.6	72.0
				< 44	NS	--	--	--	8.5	52.8	61.3
0510	188	0.0	9.5	44- 88	NS	--	--	--	16.7	55.5	72.2
				< 44	NS	--	--	--	9.8	51.3	61.1
Shot Hood (1500 ft Balloon, 74 kt)											
0116	15.5	2.5 S	1.0	< 44	NS	--	--	--	11.4	47.3	58.7
0220	36.3	0.0	2.1	< 44	NS	--	--	--	12.6	16.8	29.4
0307	71.0	0.0	4.1	< 44	NS	--	--	--	13.4	44.0	57.4
0408	110	7.5 N	6.6	< 44	NS	--	--	--	17.2	51.3	68.5
0520	123	0.5 N	8.3	< 44	NS	--	--	--	14.9	47.0	61.9
0611	159	1.5 S	8.9	< 44	NS	--	--	--	16.1	44.9	61.0
0801	258	2.5 S	12.4	< 44	NS	--	--	--	14.1	49.1	63.2
Shot Diablo (500 ft Tower, 17 kt)											
0119	15.3	6.3 N	3.1	105-125	86.8	0.2	2.3	2.5	0.3	6.7	7.0
				88-105	91.4	0.2	2.3	2.5	2.5	2.1	4.6
				44- 88	55.1	0.3	6.7	7.0	6.2	46.7	52.9
				< 44	3.8	0.4	0.3	0.7	2.6	7.4	10.0

TABLE E. 2 (contd)

Sta. No.	Miles from GZ	Miles from Midline	Fallout Time, H + hr	Size Range, microns	Pct Magnetic Fraction	Solubility					
						Magnetic			Nonmagnetic		
						H_2O	HCl	Total	H_2O	HCl	Total
						Pct of beta activity					
Shot Diablo (500 ft Tower, 17 kt) (contd)											
0202	20. 3	10. 0 S	3. 5	88-105	79. 5	0. 1	3. 5	3. 6	0. 8	5. 3	6. 1
				44- 88	87. 6	0. 2	3. 2	3. 4	1. 7	10. 8	12. 5
				< 44	6. 7	0. 4	5. 4	5. 8	1. 3	13. 9	15. 2
0312	40. 0	3. 9	5. 1	< 44	8. 6	0. 7	7. 7	8. 4	1. 6	11. 8	13. 4
0502	58. 9	21. 5 S	6. 7	44- 88	70. 9	0. 3	8. 1	8. 4	1. 0	8. 4	9. 4
				< 44	17. 9	0. 6	6. 7	7. 3	1. 3	21. 3	22. 6
Shot Shasta (500 ft Tower, 17 kt)											
0405	29. 0	19. 0 E	3. 1	88-105	57. 4	0. 1	5. 4	5. 5	2. 4	24. 6	27. 0
				44- 88	82. 8	0. 1	4. 1	4. 2	0. 6	7. 5	8. 1
				< 44	22. 8	0. 1	5. 2	5. 3	2. 0	18. 3	20. 3
0408	18. 5	18. 5 E	1. 6	< 44	6. 0	0. 0	0. 9	0. 9	0. 4	20. 6	21. 9
0617	32. 3	1. 0 W	1. 7	177-210	43. 4	0. 0	1. 6	1. 6	0. 4	5. 2	5. 6
				149-177	45. 4	0. 1	2. 5	2. 6	0. 4	6. 8	7. 2
				125-149	39. 0	0. 2	3. 1	3. 3	0. 5	6. 6	7. 1
				105-125	37. 4	0. 0	2. 4	2. 4	0. 3	5. 2	5. 5
				88-105	73. 7	0. 1	3. 3	3. 4	0. 3	5. 2	5. 5
				44- 88	97. 2	0. 1	3. 8	3. 9	0. 4	7. 4	7. 8
Shot Smoky (700 ft Tower, 44 kt)											
0107	6. 3	4. 7 S	0. 4	210-250	77. 2	0. 1	20. 3	20. 4	1. 3	56. 5	57. 8
				177-210	69. 0	0. 2	2. 5	2. 7	0. 5	19. 1	19. 6
				149-177	85. 3	0. 1	19. 4	19. 5	0. 4	21. 3	21. 7
0203	27. 9	3. 2 S	1. 3	125-149	82. 0	0. 4	24. 5	24. 9	1. 6	23. 3	24. 9
				105-125	90. 4	0. 2	17. 2	17. 4	1. 0	28. 6	29. 6
				88-105	84. 2	0. 2	19. 0	19. 2	1. 8	27. 1	28. 9
				44- 88	89. 2	0. 3	21. 9	22. 2	3. 9	52. 7	56. 6
				< 44	24. 0	0. 9	24. 9	25. 8	1. 6	29. 7	31. 3
0401	73. 3	16. 0 S	6. 0	44- 88	70. 5	0. 2	23. 7	23. 9	3. 5	39. 3	42. 8
				< 44	47. 5	0. 8	26. 9	27. 7	3. 3	37. 0	40. 3
0405	72. 9	22. 5 S	7. 0	44- 88	54. 1	1. 6	22. 6	24. 2	4. 1	45. 3	49. 4
				< 44	56. 7	0. 7	29. 4	30. 1	3. 5	39. 3	42. 8
0410	77. 5	30. 2 S	8. 5	< 44	47. 8	1. 0	32. 3	33. 3	3. 0	38. 0	41. 0
0620	92. 2	12. 5 N	3. 9	44- 88	85. 7	0. 3	27. 5	27. 8	2. 6	42. 3	44. 9
				< 44	43. 2	1. 1	32. 1	33. 2	2. 1	43. 6	45. 7
0616	96. 8	8. 0 N	4. 2	105-125	71. 8	0. 4	11. 3	11. 7	4. 8	63. 3	68. 1
				88-105	90. 7	0. 2	13. 8	14. 0	2. 7	27. 5	30. 2
				44- 88	87. 5	0. 2	20. 5	20. 7	2. 2	36. 9	39. 1
				< 44	43. 2	1. 1	25. 0	26. 1	2. 3	37. 2	39. 5
0602	100	13. 2 S	5. 8	44- 88	70. 5	0. 5	18. 9	19. 4	0. 3	14. 3	14. 6
				< 44	40. 5	0. 5	46. 5	47. 0	3. 4	46. 5	49. 9
0905	141	13. 5 S	8. 5	44- 88	54. 2	0. 3	33. 2	33. 5	3. 3	25. 1	28. 4
				< 44	48. 8	0. 3	28. 8	29. 1	1. 7	38. 4	40. 1
0919	142	25. 9 S	10. 5	44- 88	24. 7	0. 3	37. 3	37. 6	3. 4	35. 2	38. 6
				< 44	45. 1	1. 1	32. 7	33. 8	2. 1	39. 4	41. 5
0805	147	11. 1 S	7. 5	44- 88	57. 1	0. 3	24. 7	25. 0	2. 3	39. 2	41. 5
				< 44	44. 1	27. 4	19. 1	46. 5	0. 8	33. 4	34. 2